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ESTIMATION OF SMALL SYSTEM WATER TREATMENT COSTS

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This report presents cost data for unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost data are presented for 45 centralized treatment unit processes that are considered to be especially applicable to contaminant removal or to the treatment and disposal of sludges or brines produced by the treatment processes. These cost data are applicable to flows up to 3,785 m^3/d (1 mgd). Cost data are also presented for five point-of-use treatment techniques.

Construction and operation and maintenance costs are presented versus the most appropriate design parameter for the process. Construction costs were developed by summing the cost of eight individual categories: excavation and sitework; manufactured equipment; concrete; steel; installation labor; pipe and valves; electrical and instrumentation; and housing. Operation and maintenance requirements were determined individually for three categories: energy (building and process); maintenance material; and labor. All costs are presented in terms of December 1983, dollars, and a discussion is included on cost updating. A computer program is included for cost retrieval and updating.

Field operating data were collected at 25 utilities. This data is summarized in an appendix, and where applicable, the actual field data are shown on the construction and operation and maintenance plots for the individual unit processes.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research--a most vital communications link between the researcher and the user community.

The cost of constructing and operating small water treatment facilities is of considerable interest to Federal, state, and local agencies, as well as consulting engineers. This report presents construction and operation and maintenance cost data for 45 unit processes which are applicable to small systems treating flows up to 3,785 m^3/d (1 mgd). Cost information is also presented for point-of-use water treatment equipment, which can be located within each home. The processes presented in this report were selected on the basis of their general applicability to small systems, as well as on their capability to remove contaminants included in the National Interim Primary Drinking Water Regulations.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report presents cost data for unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost data are presented for 45 centralized treatment unit processes that are considered to be especially applicable to contaminant removal or to the treatment and disposal of sludges or brines produced by the treatment processes. These cost data are applicable to flows up to 3,785 m^3/d (1 mgd). Cost data are also presented for five point-of-use treatment techniques.

For each unit process included in this report, conceptual designs were formulated, and construction costs were then developed using the conceptual designs. The construction costs are presented in tabular form by eight categories: excavation and sitework; manufactured equipment; concrete; steel; installation labor; pipe and valves; electrical and instrumentation; and housing.

Construction costs are also shown graphically, plotted versus the most appropriate design parameter for the process (such as square feet of surface area for a pressure filter). This type of plot allows the data to be used with varying design criteria, such as varying filtration rates for the pressure filter costs.

Operation and maintenance requirements were determined individually for three categories: energy (building and process), maintenance material, and labor.

All costs are presented in terms of December 1983, dollars, and a discussion is included on cost updating. For construction cost, either of two methods may be used. One is the use of indices that are specific to each of the eight categories used to determine construction cost. The second is use of an all-encompassing index, such as the ENR Construction Cost Index. Operation and maintenance requirements may be readily updated or adjusted to local conditions, since labor requirements are expressed in hours per year, electrical requirements are in kilowatt-hours per year, and diesel fuel is in gallons per year. Maintenance material costs are updated using the Product Price Index for Finished Goods.

Field operating data were collected at 25 utilities by two subcontractors: Rubel and Hager, Inc., Tucson, Arizona; ACT Systems, Inc., Winter Park, Florida. Separate reports were prepared to present data collected at these 25 utilities, and these reports are summarized in Appendix B. Where applicable, the actual field data are shown on the construction and operation and maintenance plots for the individual unit processes.

This report was submitted in fulfillment of contract No. 68-03-3093 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 1981, to January 1984, and work was completed as of March 1984.

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LIST OF ABBREVIATIONS AND SYMBOLS

BOD_5 -- 5-day biochemical oxygen demand
COD -- chemical oxygen demand
$CaCO_3$ -- calcium carbonate
cu ft -- cubic feet
d -- day
D.C. -- direct current
EBCT -- empty bed contact time
ED -- electrodialysis
EDR -- electrodialysis reversal
ft -- feet
G -- velocity gradient - feet per second per foot
GAC -- granular activated carbon
gal -- gallon
gpd -- gallons per day
gpd/sq ft -- gallons per day per square foot
gpm -- gallons per minute
hr or h -- hours
kg -- kilogram
kwh -- kilowatt-hour
L -- liter
lb -- pound
Lpd -- liters per day
L/s -- liters per second
m -- meter
μm -- micro meter
m^2 -- square meter
m^3 -- cubic meter
m^3/d -- cubic meters per day
m^3/s -- cubic meters per second
mg -- milligram
mg/L -- milligram per liter
mgd -- million gallons per day
min -- minutes
mph -- miles per hour
NTU -- turbidity units
psi -- pounds per square inch (gage pressure)
RO -- reverse osmosis
sec or s -- second
scf -- standard cubic feet
SCFM -- standard cubic feet per minute
sq ft -- square feet
tdh -- total dynamic head
THM -- trihalomethane
yr or y -- year

METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
acre	4,046.7	m^2
cu ft	0.028	m^3
cu yd	0.75	m^3
°F	0.555 (°F-32)	°C
ft	0.3048	m
gal	3.785	L
gal	0.003785	m^3
gpd	0.003785	m^3/d
gpm	0.0631	L/s
gpm/sq ft	2.44	m^3/m^2/h
grains/cu ft	0.0022918	kg/m^3
hp	0.7454	kw
in	2.54	cm
kwh/sq ft/yr	2.44	kwh/m^2/y
lb	0.454	kg
lb/day	0.454	kg/d
lb/gal	0.1199	kg/L
lb/sq ft	4.88	kg/m^2
mgd	3785.	m^3/d
psi	0.0703	kg/cm^2
sq ft	0.0929	m^2
$/lb	2.2	$/kg
$/million gallons	3785.	$/$m^3$

SECTION 1

INTRODUCTION

SCOPE

This report presents construction and operation and maintenance cost data for centralized treatment techniques and point-of-use treatment techniques. The cost data are based on December 1983, costs. Treatment techniques included were selected for their ability to remove contaminants included in the National Interim Primary Drinking Water Regulations. For centralized treatment, costs are presented for 45 unit processes. The majority of these unit processes are "package" systems which are factory prefabricated and shipped to the required locations. Other processes included are chemical feed systems and sludge and brine handling techniques.

Costs are also included for five different point-of-use treatment techniques. Point-of-use treatment is used at individual homes, rather than in a central location. Point-of-use treatment may be applicable in very small systems where centralized treatment is not feasible or not economical.

A computer program is included for retrieval and updating of cost data presented in this report. Included with this program is a users manual.

The 45 centralized treatment techniques which are included in this report, and the order in which they are presented in Section 5 are:

Complete Treatment Techniques

1. Package Complete Water Treatment Systems
   - Conventional Package Complete Treatment
   - Culligan Multi-Tech System
   - Neptune Microfloc Trident System
2. Package Lime Softening

Filtration Techniques

3. Package Pressure Filtration Plants
4. Package Gravity Filtration Plants
5. Diatomite Filtration
   - Package Vacuum Diatomite Filters
   - Package Pressure Diatomite Filters
6. Slow Sand Filters

Membrane Treatment Techniques

7. Reverse Osmosis
8. Electrodialysis
9. Package Ultrafiltration

Ion Exchange and Adsorption Techniques

10. Cation Exchange Softening
11. Anion Exchange Nitrate Removal
12. Activated Alumina Fluoride Removal
13. Granular Activated Carbon Adsorption
    - Package Pressure Granular Activated Carbon Contactors
    - Package Gravity Granular Activated Carbon Contactors

Aeration

14. Diffused Air Aeration
15. Countercurrent Packed Tower Aeration
16. Spray Aeration Systems
17. Cascade Tray Aerators

Chemical Feed Systems

18. Gas Feed Chlorination Systems
19. Hypochlorite Solution Chlorination Systems
20. Pellet Feed Chlorinators
21. Erosion Feed Chlorinators
22. On-Site Hypochlorite Generation Systems
23. Chlorine Dioxide Generation and Feed Systems
24. Ozone Generation, Feed, and Contacting Systems
25. Basic Chemical Feed Systems
26. Dry Chemical Feed Systems
27. Polymer Feed Systems
28. Powdered Activated Carbon Feed Systems
29. Sulfuric Acid and Sodium Hydroxide Feed Systems
30. Potassium Permanganate Feed Systems
31. Ferric Chloride Feed Systems

Sludge and Brine Handling Techniques

32. Sludge Dewatering Lagoons
33. Sludge Disposal to Sanitary Sewers
34. Sand Drying Beds
35. Liquid Sludge Hauling by Truck
36. Dewatered Sludge Hauling by Truck
37. Brine Evaporation Lagoons

Miscellaneous Techniques

38. Water Wells
39. Package Raw Water Pumping Facilities

40. Package High-Service Pumping Facilities
41. Filter Media
42. Package Flocculator/Clarifier
43. Contact Basins - Direct Filtration Applications
44. Ultraviolet Light Disinfection
45. Clearwell Storage

The five point-of-use treatment techniques and the order in which they are presented in Section 6 are:

1. Reverse Osmosis
2. Activated Alumina
3. Granular Activated Carbon
4. Cation Exchange
5. Anion Exchange

PURPOSE AND OBJECTIVES

The principal purpose of this project was to develop and present construction and operation and maintenance cost data for centralized and point-of-use treatment techniques. The upper capacity limit of the data presented is 3785 m^3/d (1 mgd).

To increase the usefulness of the cost data, they were developed in a manner which allows raw water quality variations to be taken into account. This was done using either a process design parameter other than flow rate, using multiple tables or curves for different raw water or treatment conditions, or a combination of these two approaches.

Another objective was to verify cost data generated in the office by comparing them with cost data collected in the field. To accomplish this objective, 25 utilities encompassing a wide variety of the treatment techniques included in this report were visited. A summary of the field data collected is included in Appendix B.

APPROACH TO DEVELOPMENT OF COSTS

The cost data presented in this report have been developed in a manner which will allow maximum flexibility in their use. Contruction costs are presented versus the most appropriate design parameter which will allow designer preference, raw water quality variations, and regulatory agency loading rates to be accommodated. Although some construction costs are shown plotted versus flow, most are shown plotted versus another design parameter, such as pounds or cubic feet per day for chemical feed systems, square feet of surface area for filters, and contactor volume for ion exchange and adsorption processes. This approach gives the cost data a much higher degree of flexibility than if costs for all processes were shown plotted versus flow.

Construction costs were developed and are presented in terms of eight component categories: excavation and sitework; manufactured equipment; concrete; steel; labor (installation); pipe and valves; electrical and instrumentation; and housing.

Operation and maintenance requirements were developed and are presented in terms of process energy, building energy, maintenance material costs, and labor. Energy requirements are presented in terms of kilowatt-hours/year for electrical and gallons/year for diesel fuel. Maintenance material requirements are presented in dollars/year and labor requirements are in hours/year. Local costs for energy and labor can be readily incorporated using this approach.

A complete discussion of cost data development is included in Section 4.

SECTION 2

TECHNIQUES FOR REMOVAL OF CONTAMINANTS AND DISPOSAL OF SLUDGES AND BRINES

WATER TREATMENT

The treatment processes included within this report have been selected because they are applicable to small water treatment systems, and because they are capable of removing one or more of the contaminants included in the National Interim Primary Drinking Water Regulations (NIPDWR).

To assist in process selection for the removal of one or more of the contaminants included in the NIPDWR, Tables 1 and 2 have been prepared. These tables indicate for each contaminant, which treatment techniques are applicable, the probable maximum percentage removal for the given technique and treatment conditions, and the maximum raw water concentration of the contaminant which can be treated and still achieve the MCL. The maximum raw water concentrations are based upon the probable maximum percentage removals which are shown.

As may be observed in Tables 1 and 2, most of the slightly soluble inorganic constituents may be removed by conventional coagulation, whereas highly soluble inorganics require removal by reverse osmosis, electrodialysis or ion exchange. Organics are generally removed by adsorptive interaction with activated carbon. Although these are generalizations, it is important to recognize that there is a great degree of commonality among many contaminants, and that many treatment techniques are applicable to the removal of more than one contaminant.

It is important also to realize that even though a treatment technique may provide excellent removal of a contaminant, it may not be a practical technique from an economic perspective. One of the key purposes of this report is to provide cost information which will allow the economic comparison of different treatment technologies. Such cost comparisons are essential, since cost is a major important factor in the selection of treatment technology.

The information presented in Tables 1 and 2, particularly the probable maximum percentage removals, has been developed using a number of references. Following is a listing of applicable references for each contaminant listed in Tables 1 and 2:

Contaminant	MCL	Probable Maximum Percentage Removal	Maximum(1) Raw Water Concentration	Package Complete Treatment	Package Lime Softening	Oxidation	Reverse Osmosis(2) or Electrodialysis	Ion Exchange Anion	Ion Exchange Cation	Activated Alumina	Activated Carbon Granular	Activated Carbon Powdered	Remarks
Arsenic	0.05 mg/L												
Trivalent			---			X							Oxidize to pentavalent form and remove by one of the techniques shown.
		80%	0.25 mg/L				X						
Pentavalent		95%	1.0 mg/L	Alum pH <7.0									
		45%	0.09 mg/L	Alum pH 8.0									
		95%	1.0 mg/L	Ferric pH 6-8									
		60%	0.12 mg/L	Ferric pH 9									
		99%	5.0 mg/L		pH >10.8					pH 5-6			
		90%	0.5 mg/L				X	X (4)					
Barium	1.0 mg/L	95%	20 mg/L		pH 10-10.5			X					
		97%	33 mg/L				X						
Cadmium	0.01 mg/L	95%	0.2 mg/L	Ferric >pH 8									
		98%	0.5 mg/L		X				X				
		90%	0.1 mg/L				X						
Chromium	0.05 mg/L												
Trivalent		99%	5 mg/L	Ferric pH 6.5-8.5	pH >10.8								
		95%	1 mg/L	Alum pH 6.5-8.5									
		90%	0.5 mg/L				X						
Hexavalent		95%	1 mg/L	Ferrous Sulfate									
		90%	0.5 mg/L				X						
Fluoride	1.4-2.4 mg/L	99%	>140 mg/L										
		95%	> 14 mg/L		pH >10.6					pH 5-6			High magnesium content required.
		85%	>9.3 mg/L				X						
Lead	0.05 mg/L	97%	1.7 mg/L	Ferric pH 6-10									
		99%	5 mg/L (3)	Alum pH 6-10									
		99%	5 mg/L		pH 8.8-11.0		X						
Mercury	0.002 mg/L												
Inorganic		50%	0.004 mg/L	Ferric pH 8									
		80%	0.01 mg/L										
		70%	0.007 mg/L		pH 10.7-11						X		
		95%	0.04 mg/L				X						

TABLE 1. MATRIX OF EFFECTIVE TREATMENT TECHNIQUES FOR REMOVAL OF INORGANIC CONTAMINANTS

Contaminant	MCL	Probable Maximum Percentage Removal	Maximum[(1)] Raw Water Concentration	Package Complete Treatment	Package Lime Softening	Oxidation	Reverse Osmosis[(2)] or Electrodialysis	Ion Exchange Anion	Ion Exchange Cation	Activated Alumina	Activated Carbon Granular	Activated Carbon Powdered	Remarks
Organic		80%	0.01 mg/L									X	
		60%	0.005 mg/L				X				X		
Nitrate	10 mg/L as N	90%	100 mg/L as N					X					
		85%	66.7 mg/L as N				X						
Selenium	0.01 mg/L												
Quadravalent		90%	0.1 mg/L					X (4)					
		97%	0.33 mg/L				X						
		70%	0.033 mg/L							X			
		60%	0.025 mg/L	Ferric pH 7									
Hexavalent		97%	0.33 mg/L				X	X (5)					
Silver	0.05	85%	0.33 mg/L						X				
		93%	0.71 mg/L				X						
		80%	0.25 mg/L	Ferric pH 7-8									
		80%	0.25 mg/L	Alum pH 7-8									
		90%	0.5 mg/L		pH 11								

NOTE: Where more than one process is listed on a single line, this indicates that the processes used individually are equally effective.

FOOTNOTES: (1) This is the maximum concentration which can be treated by each technique and still meet the MCL. Concentrations are based upon average removal efficiency, and can vary widely as explained in the text.

(2) Treatment capabilities are estimated to be comparable.

(3) Removal efficiency is a function of raw water turbidity, with removal efficiency increasing as turbidity increases.

(4) Sulfate is preferentially removed.

(5) Preference for hexavalent selenium and sulfate is approximately equal. Use of anion exchange is possible if sulfate concentration is low.

TABLE 1. (Continued)

Contaminant	Probable Maximum Percentage Removable	Activated Carbon		Package Lime Softening	Cation Exchange	Reverse Osmosis or Electrodialysis	Disinfection				Package Complete Treatment	Package Filtration	Slow Sand Filtration	Aeration	Diatomaceous Earth Filtration
		Granular	Powdered				Chlorine	Chlorine Dioxide	Ozone	Chlora-mines					
Organics	99%	X												X	
	90%		X											X	
Radioactivity															
Alpha Emitters	85%			X											
	95%				X										
	95%					X									
Beta Emitters	(2)			X		X									
Coliform Organisms	>99%						X	X	X	X	Alum	X			
Turbidity	>95%										Alum	X	X		X

NOTES: (1) Where more than one process is listed on a single line, it indicates that the processes used individually are equally effective in removing the contaminant.

(2) Treatment techniques and removal efficiencies depend upon the type of radioactivity. Various isotopes of the following compounds are classified as beta and photon emitters: Barium, Cadmium Cerium, Cesium, Chromium, Cobalt, Copper, Iodine, Lanthanum, Scandium, Strontium, Yttrium, and Zirconium.

TABLE 2. MATRIX OF EFFECTIVE TREATMENT TECHNIQUES FOR REMOVAL OF ORGANICS, RADIOACTIVITY, COLIFORM ORGANISMS AND TURBIDITY

TABLE 2

Contaminant	References on Removal Efficiency of Treatment Processes
Arsenic	6,7,8,9
Barium	7,10
Cadmium	7,10,11
Chromium	7,10,12
Fluoride	7,10,13,14,15
Lead	7,10,11
Mercury	7,10,12
Nitrate	7,10,13,16,17
Selenium	6,7,10
Silver	7,10,11
Organics	7,18
Radioactivity	7
Coliform Organisms	19,20
Turbidity	19,21

TREATMENT AND DISPOSAL OF SLUDGES AND BRINES

One of the more vexing problems in water treatment plant design and operation is treatment and disposal of sludges and brines. Problems are somewhat less at small plants, due to the proportionate reduction in sludge and/or brine. Treatment and disposal techniques which are appropriate for small water treatment plants are shown as follows:

	Sludge Lagoon	Sanitary Sewer	Sand Beds	Return to Plant Headworks	Evaporation Pond
Alum Sludge	X	X	X		
Lime Sludge	X	X	X		
Diatomite Filter Sludge	X	X	X		
Filter Backwash Water	X			X	
Brine		X			X

Disposal to the watercourse which is the source of the raw water may be allowed in some cases by the state agency which is responsible for granting and enforcing NPDES (National Pollutant Discharge Elimination System) permits.

Also included within this report are costs for hauling both liquid and dewatered sludges. Mechanical dewatering processes are generally not applicable to plants less than 3,785 m^3/d (1 mgd), and are not included in this report.

SECTION 3

FIELD DATA COLLECTION PROGRAM

As a part of this project, field data collection was conducted at 25 different treatment plants. The purpose of this data collection effort was two-fold:

- To collect construction cost and operation and maintenance cost data to support, or to be used in modifying, the cost data generated using other sources.

- To supplement EPA's existing data base on utility operations and costs.

In selecting treatment plants to be visited in the data collection effort, an attempt was made to include plants which collectively utilized the majority of the treatment processes included in the cost portion of this report. Table 3 presents a listing of the 25 plants which were visited, and Table 4 lists the treatment processes which were utilized at each of these 25 plants. As shown in Table 4, many of these treatment plants utilized more than one treatment processes.

The field data collection was performed by two subcontractors: ACT Systems, Inc., of Winter Park, Florida, and Rubel and Hager, Inc., of Tucson, Arizona. ACT Systems was responsible for data collection at utilities in the Eastern U.S., and Rubel and Hager was responsible for data collection at utilities in the Western U.S.

A separate report was prepared by the subcontractors for each utility visited. Due to the extensiveness of these reports, they are not included. However, a summary of the information collected at each utility is presented in Appendix B, and certain of the information presented in Appendix B is discussed in the unit process cost write-ups presented in Section 5 of this report.

TABLE 3. UTILITIES INCLUDED IN FIELD DATA COLLECTION PROGRAM

1. Village of Western Springs, Illinois
2. Village of German Valley, Illinois
3. Village of Rouses Point, New York
4. Rockaway Township Water Department, New Jersey
5. Villa Rica Water Department, Villa Rica, Georgia
6. Borough of Rockaway, New Jersey
7. Village of Port Henry, New York
8. Village of Olympia Fields, Illinois
9. Fayette County Water System, Fayetteville, Georgia
10. Borough of Strasburg, Pennsylvania
11. Charlotte Harbour Water Association, Harbor Heights, Florida
12. Bryn Mawr Water Company, Vero Beach, Florida
13. Wurtsmith Air Force Base, Michigan
14. Town of Gila Bend, Arizona
15. Dell City, Texas
16. City of Bronson, Kansas
17. City of Richmond, Kansas
18. Jefferson County Rural Water District No. 11, Kansas
19. City of Rialto, California
20. City of Safford, Arizona
21. Davis Dam, Bullhead City, Arizona
22. City of Castle Dale, Utah, Castle Valley Special Service District
23. City of Ferron, Utah, Castle Valley Special Service District
24. Orangeville, Utah, Castle Valley Special Service District
25. McFarland, California, McFarland Mutual Water Company

Treatment Process	Utility 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Lime Softening	X																									
Gravity Sand Filtration	X	X			X				X												X		X	X	X	
Pressure Sand Filtration														X								X				
Packed Tower Aeration		X		X									X													
Ion Exchange Softening		X																								
Pressure D. E. Filters			X					X												X						
GAC (Pressure)				X		X							X													
Chlorine Dioxide					X				X																	
Slow Sand Filters							X																			
Ozone										X																
Reverse Osmosis											X	X														
Activated Alumina															X											
Electrodialysis																X										
Package Complete Treatment																	X	X	X							
Anion Exchange Nitrate Removal																										X

NOTE: Utilities are listed using a corresponding numbering system in Table 1.

TABLE 4. TREATMENT PROCESS INCLUDED IN FIELD DATA COLLECTION PROGRAM

SECTION 4

APPROACH TO DEVELOPMENT OF COST DATA

CONSTRUCTION COST DATA

The construction cost data presented in this report are based on December 1983, costs. The data were developed using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. When unit cost takeoffs were used to determine costs from actual and conceptual designs, estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards, Mean's Building Construction Cost Data, and the Dodge Guide for Estimating Public Works Construction Costs were utilized.[1,2,3] Within each individual process write-up, conceptual design information is presented, as are assumptions which were made during the development of the cost data.

Users should recognize that the construction cost data represents the base construction cost, and not the capital cost. The construction cost data may have to be increased for site-specific conditions or requirements, such as standby power or unusual subsurface conditions. To convert the construction cost data into capital cost for an entire plant, the cost data must be aggregated for the individual processes, and then adjustments must be added for the following:

- Overall sitework, interface piping, and roads
- General contractors' overhead and profit
- Engineering
- Land
- Legal, fiscal, and administrative costs
- Interest during construction

Addition of costs for these items, where applicable, will yield the capital cost for a treatment system.

The construction cost data were developed by determining and then aggregating the cost of eight principal components, which were selected to facilitate cost development and to aid in subsequent cost updating (discussed elsewhere in this section). This division will also be helpful where costs are being adjusted for site-specific, geographic, and other special conditions. The eight categories include the following general items:

Excavation and Sitework

This category includes work related only to the individual treatment process, and does not include general sitework such as fencing, sidewalks, roads, driveways, landscaping, or lighting.

Manufactured Equipment

This category includes the cost of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

Concrete

This category includes the delivered cost of ready-mix concrete and concrete-forming materials. The slab or foundation for buildings is included in this category.

Steel

This category includes reinforcing steel for concrete and miscellaneous steel not included within the manufactured equipment category.

Labor

The labor associated with installing manufactured equipment, installing pipe and valves, installing electrical equipment and instrumentation, constructing concrete forms, and placing concrete and reinforcing steel is included in this category.

Pipe and Valves

Pipe, valves, and fittings are included in this category.

Electrical Equipment and Instrumentation

The cost of process electrical equipment, wiring, and instrumentation associated with the process equipment is included in this category.

Housing

In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, lighting, and normal convenience outlets.

The subtotal of the costs for these eight categories includes the cost of material and equipment purchase and installation, and subcontractor's overhead and profit. To this subtotal, a 15% allowance was added to cover miscellaneous items not included in the cost takeoff, as well as contingency items. Experience at many water treatment facilities has indicated that this 15% allowance is reasonable. Although blanket application of this 15% allowance may result in some minor inequities between processes, these are generally balanced out, during the combination of costs for individual processes into a treatment system.

The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, construction costs for gravity and pressure filters are presented versus total square feet of filter surface area, ozone generation system costs are presented versus pounds per day of feed capacity, and diffused aeration system costs are presented versus basin volume, with two different basin depths and three different rates of air addition per square foot of basin area incorporated. Use of such key design parameters allows the cost data to be utilized with greater flexibility than if cost information were plotted versus flow. However, for some processes, flow is the most appropriate design parameter. Examples of such processes include reverse osmosis, ultraviolet light disinfection, and tray aeration.

Examples are presented in Section 7 for the use of the construction cost data presented in this report. These examples illustrate the addition to the construction cost of various factors discussed previously, to produce the total capital cost for a project.

OPERATION AND MAINTENANCE COSTS AND REQUIREMENTS

Operation and maintenance requirements were developed for energy, maintenance material, and labor. The energy category includes process electrical energy, building electrical energy, and diesel fuel. The operation and maintenance requirements were determined from operating data at existing plants, to the extent possible. Where such information was not available, assumptions were made based on the experience of both the author and the equipment manufacturer, and such assumptions are stated in the individual process write-ups.

Electrical energy requirements were developed for both process energy and building-related energy, and they are presented in terms of kilowatt-hours per year. Process energy is energy required for operation of motors, controls, and instrumentation. Building energy is energy required for lighting, ventilation and heating of buildings which house treatment processes. Requirements for building energy, on a unit-area basis, are variable, depending upon several factors:

- Hours per day of lighting
- Geographic location of the building
- Interior height of the building

Appendix A presents a discussion of building energy requirements, and a summary for 21 major cities across the U.S. Requirements are presented for both 10 and 14-foot interior building heights, and are based upon a lighting requirement of three hours per day. The average is 156 kwh/m^2/yr (14.5 kwh/sq ft/yr) for a 3.05 m (10 ft) high ceiling height and 209.8 kwh/m^2/yr (19.5 kwh/sq ft/yr) for a 4.27 m (14 ft) ceiling height. Conceptual designs for each process indicate the ceiling height which is utilized. The computer program which was developed as a part of this project allows use of these energy requirements, or other requirements selected by the program user.

For several processes, requirements for diesel fuel are included. In these processes, the diesel fuel is used for trucks, front-end loaders, or other mobile equipment.

When using the energy data, the process design parameter should be used to determine building energy, and the process operating parameter should be used to determine process energy and diesel fuel requirements.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items are valves, motors, instrumentation and other process items of similar nature. The maintenance material requirements do not include the cost of chemicals required for process operation. Chemical costs must be added separately, as will be shown in the examples in Section 7. The process operating parameter should be used to determine maintenance material requirements.

Labor requirements include both operation and maintenance labor, and are presented in terms of hours-per-year. The process operating parameter should be used to determine the labor requirement.

Total operation and maintenance cost is a composite of the energy, maintenance material, and labor costs. To determine annual energy costs, unit costs of $0.07/kwh of electricity and $1.10/gal of diesel fuel were utilized. The labor requirements were converted to an annual cost using an hourly labor rate of $11.00/hr, which includes salary and fringe benefits. The computer program which was developed as a portion of this project allows utilization of other unit costs for energy and labor.

LOWER LIMIT OF COST DATA APPLICABILITY

For most unit processes, both construction or operation and maintenance requirements tend to reach a minimum, even though the process is operated at less than the design capacity or rate. For example, the smallest conventional package complete treatment plant has a filter area of 0.186 m^2 (2 sq ft). If operated at a filtration rate of 12.2 $m^3/m^2/h$ (5 gpm/sq ft) this plant has a capacity of 54.5 m^3/d (14,400 gpd), while if it is operated at a filtration rate of 4.88 $m^3/m^2/h$ (2 gpm/sq ft), it has a treatment capacity of 22 m^3/d (5800 gpd). These flow rates assume continuous twenty-four hours per day production, which may not be true in all situations. Fewer hours of operation per day will result in even lower daily production. However, regardless of the filtration rate or the hours per day operated, the construction cost would be the same. This is true for many of the unit processes included in this report. Once the smallest practical size is reached, no further reductions in construction cost occur, regardless of a further reduction in the design parameter.

In a similar sense this is also true for operation and maintenance requirements. For the smallest available size for a particular process, certain minimal operation and maintenance requirements must be met regardless of the flow treated. This is generally apparent by a leveling out of the energy, maintenance material, and labor requirements as the process operating parameter decreases. With smaller operating parameters, further reductions in requirements are not evidenced.

Since costs were developed for the smallest practical treatment unit for each process, construction costs for smaller design parameters would be the same as the smallest construction cost shown.

UPDATING COSTS TO TIME OF CONSTRUCTION

Continued usefulness of the cost data presented in this report depends on the ability of the costs to be updated to reflect increases or decreases in the prices of the various components. Most engineers and planners are accustomed to updating costs using one all-encompassing index, which is developed by tracking the cost of specific items and then proportioning these costs according to a predetermined ratio. They key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indices are not understood by many users and/or are inadequate for application to water treatment plant construction.

The most frequently utilized single indices in the construction industry are the ENR (Engineering News-Record) Construction Cost Index (CCI) and ENR Building Cost Index (BCI). These ENR indices were started in 1921 and were intended for general construction cost monitoring. The CCI consists of 200 hrs of common labor, 2,500 lbs of structural steel shapes, 1.128 tons of Portland cement, and 1,008 board feet of 2 x 4 lumber. The BCI consists of 68.38 hrs of skilled labor plus the same materials included in the CCI. The large amount of labor included in the CCI was appropriate before World War II; however, on most contemporary construction, the index labor component is far in excess of actual labor requirements.

To update the construction cost using the CCI (1967 average = 100), which was 383.06 in December, 1983, the following formula may be utilized:

$$\text{Updated Cost} = \text{Construction Cost}\left(\frac{\text{Current CCI}}{383.06}\right)$$

This cost updating approach is one of the two updating options which can be used in the computer program developed for this project.

Although key advantages of the ENR indices include their availability, their simplicity, and their geographical specificity, many engineers and planners believe that these indices are not applicable to water treatment plant construction. The rationale for this belief is that the indices do not include mechanical equipment or pipe and valves that are normally associated with such construction, and the proportional mix of materials and labor is not specific to water treatment plant construction.

An approach that may be utilized to overcome the shortcomings of the ENR indices relative to water treatment plant construction is to apply specific indices to the major cost components of the construction cost data. This approach allows the costs to be updated using indices specific to each category and weighted according to the dollar significance of the category. For the eight major categories of construction cost, the following Bureau of Labor Statistics (BLS) and ENR indices were utilized as a basis for the cost curves included in this report.

Cost Component		December 1983 Value of Index
Excavation and Sitework	ENR Skilled Labor Index (1967 Average = 100)	368.68
Manufactured Equipment	BLS General Purpose Machinery and Equipment - Commodity Code 114	309.3
Concrete	BLS Concrete Ingredients and Related Products - Commodity Code 112	317
Steel	BLS Steel Mill Products - Commodity Code 1017	359.5
Labor, Installation	ENR Skilled Labor Index (1967 Average = 100)	368.68
Pipe and Valves	BLS Miscellaneous General Purpose Equipment - Commodity Code 1149	327.0
Electrical, Instrumentation	BLS Electrical Machinery and Equipment - Commodity Code 117	243.7
Housing	ENR Building Cost Index (1967 Average = 100)	356.30

The above indices were obtained from Table 6 of the publication "Producer Prices and Price Indexes for December, 1983" and the Engineering News-Record.[4],[5]

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices and the requirement for use of seven indices rather than a single index.

When a construction cost is obtained from one of the cost curves, and it is desired to update the cost using the two ENR and the five BLS indices, the construction cost must be disaggregated into each of the eight (in certain cases there are less than eight) component categories. One method of accomplishing this breakdown is to utilize all the detailed cost estimates included in the construction cost table to determine the average percent of the subtotal construction cost for each of the eight (or fewer) construction cost components. The appropriate index for each component can then be used to update the component cost. For example, in the construction cost table for Package Pressure Filtration Plants (Table 25 of this report) the sum of each of the seven individual components and the percentage each component represents of the total is:

	Sum From the Six Designs in Table 25	Weighted Percentage of Subtotal Costs
Excavation and Sitework	22,700	3.56%
Manufactured Equipment	297,600	46.63%
Concrete	32,400	5.08%
Labor, Installation	60,400	9.46%
Pipe and Valves	27,000	4.23%
Electrical, Instrumentation	76,200	11.94%
Housing	121,900	19.10%
	638,200	100.00%

If a cost of $155,000 was obtained from the construction cost curve, an updated construction cost could be calculated using the approach shown following:

Excavation and Sitework $= 0.0356\ (\$155{,}000) \left(\frac{\text{Current Index}}{368.68}\right) = \$\underline{\hspace{2cm}}$

Manufactured Equipment $= 0.4663\ (\$155{,}000) \left(\frac{\text{Current Index}}{309.3}\right) = \$\underline{\hspace{2cm}}$

Concrete $= 0.0508\ (\$155{,}000) \left(\frac{\text{Current Index}}{317}\right) = \$\underline{\hspace{2cm}}$

Labor, Installation $= 0.0946\ (\$155{,}000) \left(\frac{\text{Current Index}}{368.68}\right) = \$\underline{\hspace{2cm}}$

Pipe and Valves $= 0.0423\ (\$155{,}000) \left(\frac{\text{Current Index}}{327.0}\right) = \$\underline{\hspace{2cm}}$

Electrical, Instrumentation $= 0.1194\ (\$155{,}000) \left(\frac{\text{Current Index}}{243.7}\right) = \$\underline{\hspace{2cm}}$

Housing $= 0.1910\ (\$155{,}000) \left(\frac{\text{Current Index}}{356.30}\right) = \$\underline{\hspace{2cm}}$

Subtotal = $ ________
Design Contingencies at 15% =
Updated Construction Cost =

Understandably, this is a tedious procedure to perform manually, particularly if there are several processes being updated. Thus, many users of this cost data will doubtless select use of the ENR CCI approach for cost updating. The computer program developed as a part of this project allows use of either approach, and definitely simplifies updating using the BLS indices.

Updating of total operation and maintenance costs may be accomplished by updating the three individual components: energy, labor, and maintenance material. Energy and labor are updated by applying the current unit costs to the kilowatt-hour, diesel fuel and labor requirements obtained from the energy and labor curves. Maintenance material costs, which are presented in terms of dollars per year, can be updated using the Producer Price Index for Finished Goods, which can be found in Table 1 of Reference 4. The maintenance material costs in this report are based on a December 1983, Producer Price Index for Finished Goods of 287.1.

SECTION 5

COST DATA

INTRODUCTION

This section contains cost data for 45 treatment techniques applicable to centralized treatment. The treatment techniques are presented in the same order as they were listed in Section 1, page 1. These cost data were developed using the concepts discussed in Section 4.

PACKAGE COMPLETE WATER TREATMENT SYSTEMS

Package complete systems provide flocculation, clarification, and filtration. Conventional package plants generally integrate all of these operations into a single factory-built, steel shell package. Subsequent plant expansions are accomplished by adding additional treatment modules in a flow configuration parallel to the original installation.

Recently, two manufacturers have begun marketing package complete treatment units which replace the conventional flocculation and clarification stages with a fixed medium technique. One manufacturer (Neptune Microfloc) uses an upflow clarifier which contains an adsorption media of irregularly shaped polypropylene material. To prevent the adsorption media from being washed out of the adsorption clarifier during normal operation or backwash/flushing of the clarifier, a media retainer is located on the top of the unit. A second manufacturer (Culligan), uses a downflow contact flocculation unit called a depth clarifier. This unit is filled with a specially graded mineral material, and removal of turbidity occurs by contact with the surface of the media. A multi-media filter is used following the depth clarifier.

Both of these units are designed for addition of alum and polymer prior to the clarification stage. Also, both manufacturers claim that less coagulant is necessary than in conventional package plants, because a filterable floc requires less coagulant than a settleable floc.

Cost data in the following sections are presented for conventional package complete plants, the Neptune Microfloc Trident system, and the Culligan Multi-Tech system.

CONVENTIONAL PACKAGE COMPLETE TREATMENT

Introduction

Conventional package complete treatment units are factory fabricated plants which provide flocculation, settling, and filtration. Plants are skid mounted and require only raw water, product water, backwash water supply, waste to drain, electrical, and chemical feed hookups.

A typical plant includes provisions for feeding alum for coagulation and polymer as a coagulant aid. Liquid hypochlorite feed equipment can also be included. Manufacturers can also make provision for the feed of other chemicals such as powdered activated carbon, potassium permanganate, soda ash, or low dosages of lime.

A typical flow configuration consists of chemical addition, a flash mix chamber, flocculation chamber, settling, and filtration. Typically, flash mixing is accomplished by turbulence created by the feed water entering the flash mix chamber. Flocculation is provided by a mechanical mixer, and the settling compartment commonly uses tube settlers to enhance settling. Filtration is through mixed-media, capable of filtration rates up to 12.2 $m^3/m^2/h$ (5 gpm/sq ft). An integral pump may be included to pump product water to the clearwell, although in many cases such pumping is not required because the clearwell is located at a lower level than the treatment plant. The clearwell is not an integral part of the plant, and must be provided separately.

Filter backwash water supply pumps are also an integral part of the package plant, although backwash water storage is not. A separate storage tank must be provided for backwash water, and this tank may also act as the product water clearwell. Filter backwash is automatically initiated by headloss through the filter, although manual initiation is also possible. A time clock can also be added for initiation of filter backwash, but this is generally not part of the standard equipment package.

To determine the adequacy of the coagulant dose, a pilot filter can be utilized. A small quantity of raw water is pumped from the flash mix chamber directly to the pilot filter, and the turbidity of the pilot filter product water is continuously measured with a turbidimeter.

When pilot filter product water exceeds a pre-set level, an alarm is sounded. In some cases, two pilot filters are used, with the second pilot filter being placed on-line when the first is being backwashed. Additional sophistication is obtained by integrating the pilot filter turbidity readout with a control system which varies the coagulant dosage to obtain the pre-set product water clarity. Use of pilot filters and automatic coagulant dosage control results in a savings in operator time, a savings in coagulant chemicals, and optimization of product water quality.

Impact of Raw Water Quality on Treatment Cost

Raw water quality impacts the quantity of coagulant and coagulant aid required, and can also impact allowable flow through a given plant. As raw water turbidity, suspended solids, and bacterial concentration increase, higher levels of alum and polymer are required, at a resultant higher treatment cost. Under these same conditions, the filtration cycle is shortened, requiring more frequent backwash and less production of product water.

Also, for extremely poor quality water, it may be necessary to operate at filtration rates less than 12.2 $m^3/m^2/h$ (5 gpm/sq ft). This would increase treatment cost per unit of product water.

Construction Costs

Costs were developed for prefabricated package water treatment plants designed with rapid mix, flocculation, settling including tube settlers, and mixed media filtration. These prefabricated units are constructed of steel and are free standing units. For total filter surface areas of 3.72 m^2 (40 sq ft) and larger, two parallel treatment units are used. Conceptual designs showing housing requirements and the treatment capacities of the filters at 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft) are shown in Table 5. The 12.2 $m^3/m^2/h$ (5 gpm/sq ft) design rating for the filters represents a generally accepted balance between filtered water quality and the length of the filter run. However, lower filtration rates may be necessary during periods of poor raw water quality.

TABLE 5. CONCEPTUAL DESIGNS FOR CONVENTIONAL PACKAGE COMPLETE TREATMENT

				Treatment Capacity, gpd	
Filter Area, sq ft	Dimensions of Treatment Unit, LxWxH, ft	Housing LxWxH, ft	Housing Area, sq ft	Filtration Rate = 2 gpm/sq ft	Filtration Rate = 5 gpm/sq ft
2	6.5x3.5x5	20x15x10	300	5,800	14,400
12	10x8x7.5	20x15x14	300	34,600	86,400
20	16x7.5x7.5	30x15x14	450	57,600	144,000
40	23x10x7	40x25x14	1000	115,200	288,000
112	27.5x10x8	50x25x14	1250	322,600	806,400
150	33x10x8	60x25x14	1500	432,000	1,080,000

Note: Two parallel units are used for filter areas of 40 sq ft and above. Dimensions shown for the treatment unit are for both units.

Chemical facilities are included for alum and polymer storage and feed. Each chemical is stored in a separate polyethylene tank equipped with a mixer. Chemicals are metered to their respective points of application using diaphragm type metering pumps.

Backwashing of these treatment facilities is automatic, according to filter headloss. No provision is included for pilot filters or automatic control of the coagulant dosage. All treatment facilities are totally enclosed, with housing dimensions and square footage as shown in Table 5. A layout of a typical facility is shown in Figure 1.

Cost estimates for plants with filter areas between 0.19 and 13.9 m^2 (2 and 150 sq ft) are shown in Table 6 and in Figure 2. These costs are for the package treatment unit only, and do not include facilities for raw water pumping, clearwell storage, or finished water pumping.

Operation and Maintenance Requirements and Costs

Process energy requirements are for chemical mixers, chemical feed pumps, mechanical flocculators, backwash pumping, and where applicable, surface wash pumping. Chemical feed pumps were considered to operate 24 hours/day, while chemical mixers are only operated for 15 to 30 minutes following preparation of a new solution. Backwash was considered to last for seven minutes at a rate of 36.6 $m^3/m^2/h$ (15 gpm/sq ft). The three larger plant sizes are equipped with surface wash rated at 3.5 kg/cm^2 (50 psi) which were assumed to operate for 4 minutes per backwash. Process energy requirements were calculated for both one and two backwashes per day, and for filtration rates of both 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft). Process energy for influent pumping and product water pumping is not included.

Building energy is required for heating, ventilation and lighting, with the latter assumed to be 3 hours/day. Building energy requirements are 156 $kwh/m^2/y$ (14.5 kwh/sq ft/yr) for buildings 3.05 m (10 ft) high, and 209.8 $kwh/m^2/y$ (19.5 kwh/sq ft/yr) for buildings 4.27 m (14 ft) high.

Maintenance materials are for replacement of mechanical and electrical components which either wear out or break down during normal operations. Chemical costs are not included in maintenance material costs, and must be added separately. A guide to typical chemical costs is included in the following section.

Labor requirements are for both maintenance and operation, with the majority of labor being required for operation. The operator is required, on a daily basis, to maintain chemical storage tanks filled with chemicals in the proper concentration, to make laboratory measurements for determination of chemical dosage rates and to assure correct chemical feed rates, and to perform other routine laboratory testing as required. Labor requirements increase when the filtration rate increases, since more labor is required for chemical preparation. Some maintenance items may also be required on a daily basis, as will general housekeeping.

Operation and maintenance requirements and costs are summarized in Table 7.

Typical Chemical Requirements and Costs

Both chemical costs (including freight) and chemical requirements vary widely between plants. However, in order to present a typical cost, the following unit chemical costs and dosages were used to generate the typical chemical costs shown in Table 8. Chemical dosages vary widely between different

TABLE 6. CONSTRUCTION COST SUMMARY FOR CONVENTIONAL PACKAGE COMPLETE TREATMENT

Cost Category	Filter Area, sq ft 2	12	20	40	112	150
Excavation and Sitework	$ 3,500	$ 3,500	$ 4,700	$ 5,800	$ 7,000	$ 9,300
Manufactured Equipment	31,000	44,900	53,500	111,300	176,600	190,500
Concrete	1,000	1,000	1,500	4,500	5,700	6,800
Labor, Installation	9,900	14,700	17,500	36,400	57,800	62,400
Pipe and Valves	4,200	8,300	10,400	20,900	29,200	41,700
Electrical, Instrumentation	3,200	4,500	5,300	11,100	17,600	19,000
Housing	18,600	18,600	23,400	45,000	47,500	52,500
Subtotal	71,400	95,500	116,300	235,000	341,400	382,200
Design Contingencies	10,700	14,300	17,400	35,300	51,200	57,300
Total	$82,100	$109,800	$133,700	$270,300	$392,600	$439,500

TABLE 7. OPERATION AND MAINTENANCE SUMMARY FOR CONVENTIONAL PACKAGE COMPLETE TREATMENT

Filter Area, sq ft	Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Filtration Rate = 2 gpm/sq ft and one backwash/day							
2	5,800	4,400	500	4,900	900	425	5,900
12	34,600	5,900	2,000	7,900	1,400	570	8,200
20	57,600	8,800	2,100	10,900	1,600	640	9,400
40	115,200	19,500	3,900	23,400	3,300	845	14,200
112	322,600	24,400	5,300	29,700	5,300	1,220	20,800
150	432,000	29,300	5,800	35,100	5,700	1,430	23,900
Filtration Rate = 2 gpm/sq ft and two backwashes/day							
2	5,800	4,400	500	4,900	1,200	445	6,400
12	34,600	5,900	2,000	7,900	1,700	595	8,800
20	57,600	8,800	2,200	11,000	2,000	670	10,100
40	115,200	19,500	4,000	23,500	4,200	880	15,500
112	322,600	24,400	5,700	30,100	6,600	1,250	22,500
150	432,000	29,300	6,300	35,600	7,100	1,470	25,800
Filtration Rate = 5 gpm/sq ft and one backwash/day							
2	14,400	4,400	500	4,900	900	610	8,000
12	86,400	5,900	2,000	7,900	1,400	750	10,200
20	144,000	8,800	2,100	10,900	1,600	820	11,400
40	288,000	19,500	3,900	23,400	3,300	1,340	19,700
112	806,400	24,400	5,300	29,700	5,300	1,400	22,800
150	1,080,000	29,300	5,800	35,100	5,700	1,610	25,900
Filtration Rate = 5 gpm/sq ft and two backwashes/day							
2	14,400	4,400	500	4,900	1,200	630	8,500
12	86,400	5,900	2,000	7,900	1,700	775	10,800
20	144,000	8,800	2,200	11,000	2,000	850	12,100
40	288,000	19,500	4,000	23,500	4,200	1,060	17,500
112	806,400	24,400	5,700	30,100	6,600	1,440	24,600
150	1,080,000	29,300	6,300	35,600	7,100	1,650	27,800

Note: Total cost is based on $0.07/kwh of electrical energy and $11/hour of labor. Twenty-four hour/day operation is assumed.

TABLE 8. TYPICAL CHEMICAL COSTS FOR CONVENTIONAL PACKAGE COMPLETE TREATMENT

Average Plant Flow Rate, gpd	Alum Use lb/yr	Alum Cost $/yr	Polymer Use lb/yr	Polymer Cost $/yr	Chlorine Use lb/yr	Chlorine Cost $/yr	Total Chemical Cost, $/yr
14,400	400	60	4.4	10	130	50	120
86,400	2,600	340	26	80	800	300	720
144,000	4,400	570	44	130	1,300	480	1,180
288,000	8,800	1,140	88	260	2,600	960	2,360
806,400	24,500	3,190	245	740	7,400	2,740	6,670
1,080,000	30,700	3,990	307	920	9,200	3,400	8,310

Notes: 1. Chemical dosages vary between water supplies and chemical costs vary with geographical locations. The above costs represent typical costs, and predictably will vary between water supplies.

2. Costs for chemicals are: Alum - $0.13/lb; Polymer - $3.00/lb; and Chlorine - $0.37/lb.

waters, and chemical costs vary with geographical location and the quantity of chemicals purchased. The following represent average dosages and costs.

Chemical	Dosage	Cost
Alum	10 mg/L	$0.13/lb
Polymer	0.1 mg/L	$3.00/lb
Chlorine	3 mg/L	$0.37/lb

Field Data Collection

Field operating data was collected at five plants which used conventional package complete treatment. These five locations were Bronson, Kansas, Richmond, Kansas, Jefferson County Rural Water District No. 11, Kansas, Ferron, Utah, and Orangeville, Utah. At a sixth plant in Castle Dale, Utah, comparable processes are used, but the plant was not a package plant.

Each of the three plants in Kansas had a design capacity of 545 m^3/d (0.144 mgd), and operating flows were 219.9 m^3/d (0.058 mgd) at Bronson, 234.8 m^3/d (0.062 mgd) at Richmond, and 30.28 m^3/d (0.008 mgd) at Jefferson County Rural Water District No. 11. The total filter area at each plant was 1.86 m^2 (20 sq ft). The backwash frequency was not noted in the field data collection reports.

A comparison of field operating data and Figures 3 and 4, assuming a filtration rate of 4.88 $m^3/m^2/h$ (2 gpm/sq ft) and one backwash per day, is as follows:

	Field Data			Data From Figures 3 and 4
	Bronson	Richmond	Jefferson County	
Electrical Energy, kwh/hr				
Process	-	-	-	2,000
Building	-	-	-	6,200
Total	49,650	56,900	29,480	8,200
Maintenance Material, $/yr	3,080	3,930	400	1,800
Labor, hr/yr	263	690	510	625

The total energy requirements for the three plants are believed to be higher than Figure 3, because the field data included raw water and product water pumping. At Bronson however, the field data total energy does not include building heating, as propane is used for building heating. Variations in field data maintenance material requirements and Figure 3 maintenance material requirements are felt to be the result of two factors: methods used by the utilities to calculate maintenance material requirements; and in the case of Jefferson County, operation of the plant at less than 6% of design capacity. Bronson expressed all fixed costs (including propane, fuel, and telephone) as maintenance material, while Richmond estimated maintenance material requirements at 30% of the total water/sewer utility cost. Maintenance material costs are probably low at Jefferson County because the plant operated at less than 6% of design capacity. There is no apparent explanation for the low labor requirement at Bronson.

Ferron and Orangeville, Utah, both used conventional package complete treatment. At Ferron, the plant has a design capacity of 3,785 m^3/d (1 mgd), an operating flow rate of 2,135 m^3/d (0.564 mgd), and a total filter area of 29.7 m^2 (320 sq ft). The Orangeville plant also had a design capacity of 3,785 m^3/d (1 mgd), while the operating flow rate was 939 m^3/d (0.248 mgd) and the total filter area was 20.81 m^2 (224 sq ft). The backwash frequency was not noted in the field data collection reports for either plant.

A comparison of the field operating data and Figures 3 and 4, assuming a filtration rate of 4.88 $m^3/m^2/h$ (2 gpm/sq ft) and one backwash per day, is as follows:

	Ferron		Orangeville	
	Field Data	Data From Figures 3 and 4	Field Data	Data From Figures 3 and 4
Electrical Energy, kwh/hr				
Process	-	12,000	-	10,000
Building	-	50,000	-	40,000
Total	256,460	62,000	189,400	50,000
Maintenance Material, $/yr	2,500	9,000	2,910	8,000
Labor, hr/yr	730	1,600	730	1,400

Both utilities included product water pumping in total electrical requirements, which may be why electrical requirements are greater than in

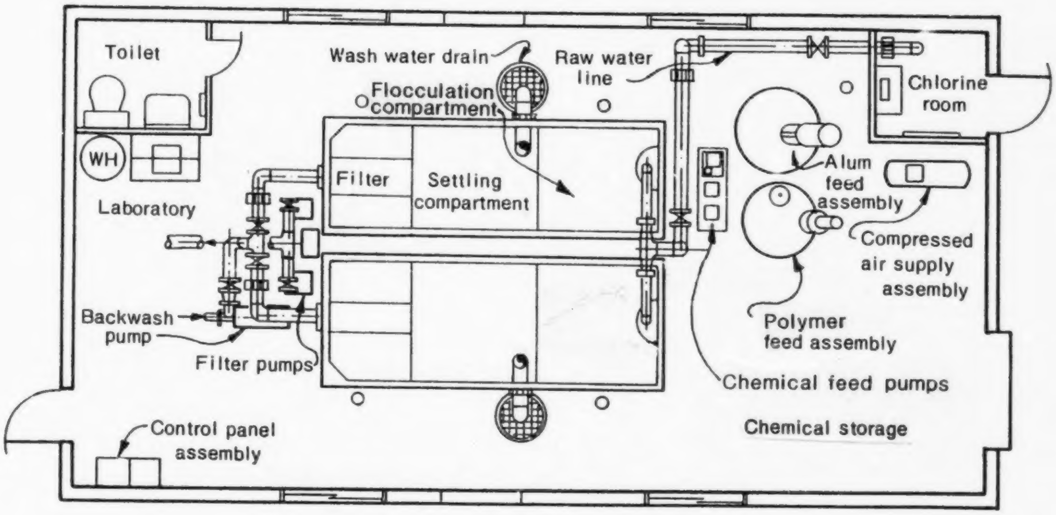
Figure 3. There is no apparent reason for differences in maintenance material, relative to Figure 3, except that both plants are operating at significantly less than the design capacity. Field labor requirements were based upon an estimate of two hours per day, which is significantly less than in Figure 4.

The plant at Castle Dale, Utah, is not a package plant, but it does use all of the treatment processes incorporated into a conventional package complete plant. Treatment processes include a flocculator/clarifier with tube settlers, and gravity, mixed-media filters. The filter structure is constructed of concrete, rather than steel as in a package plant, and low lift pumping is used between the flocculator/clarifier and the filters. The plant has a design capacity of 4920 m^3/d (1.3 mgd) and operates at 1840 m^3/d (0.486 mgd).

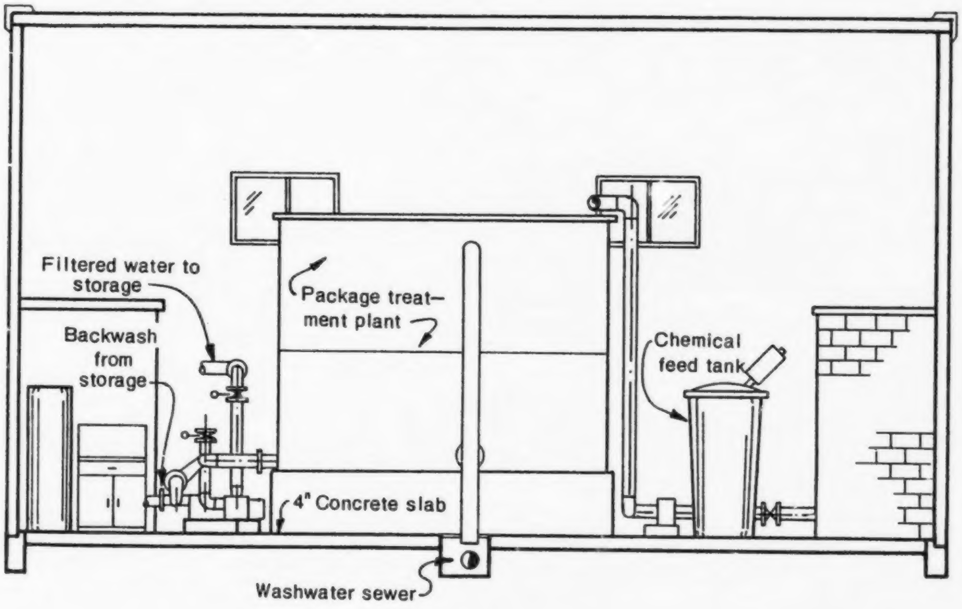
A comparison of field operating data and data from Figures 3 and 4 is shown following. Field data is based upon filter backwash every two days, while data from Figures 3 and 4 is based upon one backwash per day.

	Field Data	Data From Figures 3 and 4
Electrical Energy, kwh/hr		
Process	-	12,000
Building	-	47,000
Total	269,000	59,000
Maintenance Material, $/yr	5,020	10,000
Labor, hr/yr	1,095	1,500

Field data process electrical includes low head in-plant pumping and product water pumping. Inclusion of this pumping energy is a cause of the discrepancy between field data and Figure 3. There is no explanation for differences in maintenance material and labor (field data is an estimate based on 3 hours/day).


Toilet
Wash water drain
Raw water line
Flocculation compartment
Chlorine room
WH
Filter
Settling compartment
Alum feed assembly
Laboratory
Compressed air supply assembly
Backwash pump
Polymer feed assembly
Filter pumps
Chemical feed pumps
Control panel assembly
Chemical storage

PLAN


Filtered water to storage
Package treatment plant
Backwash from storage
Chemical feed tank
4" Concrete slab
Washwater sewer

ELEVATION

Figure 1. Typical conventional package complete treatment plant installation.

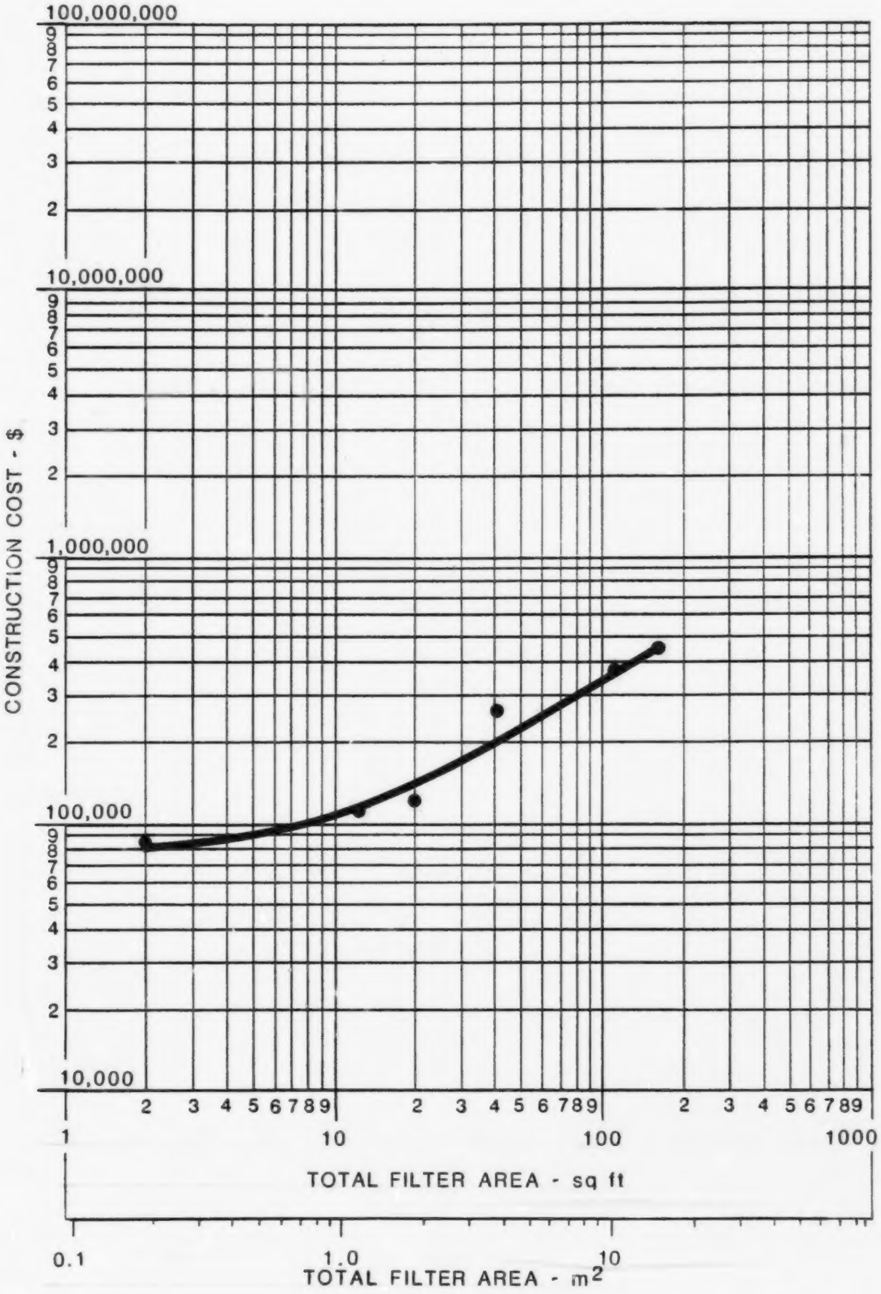


Figure 2. Construction cost for conventional package complete treatment plants.

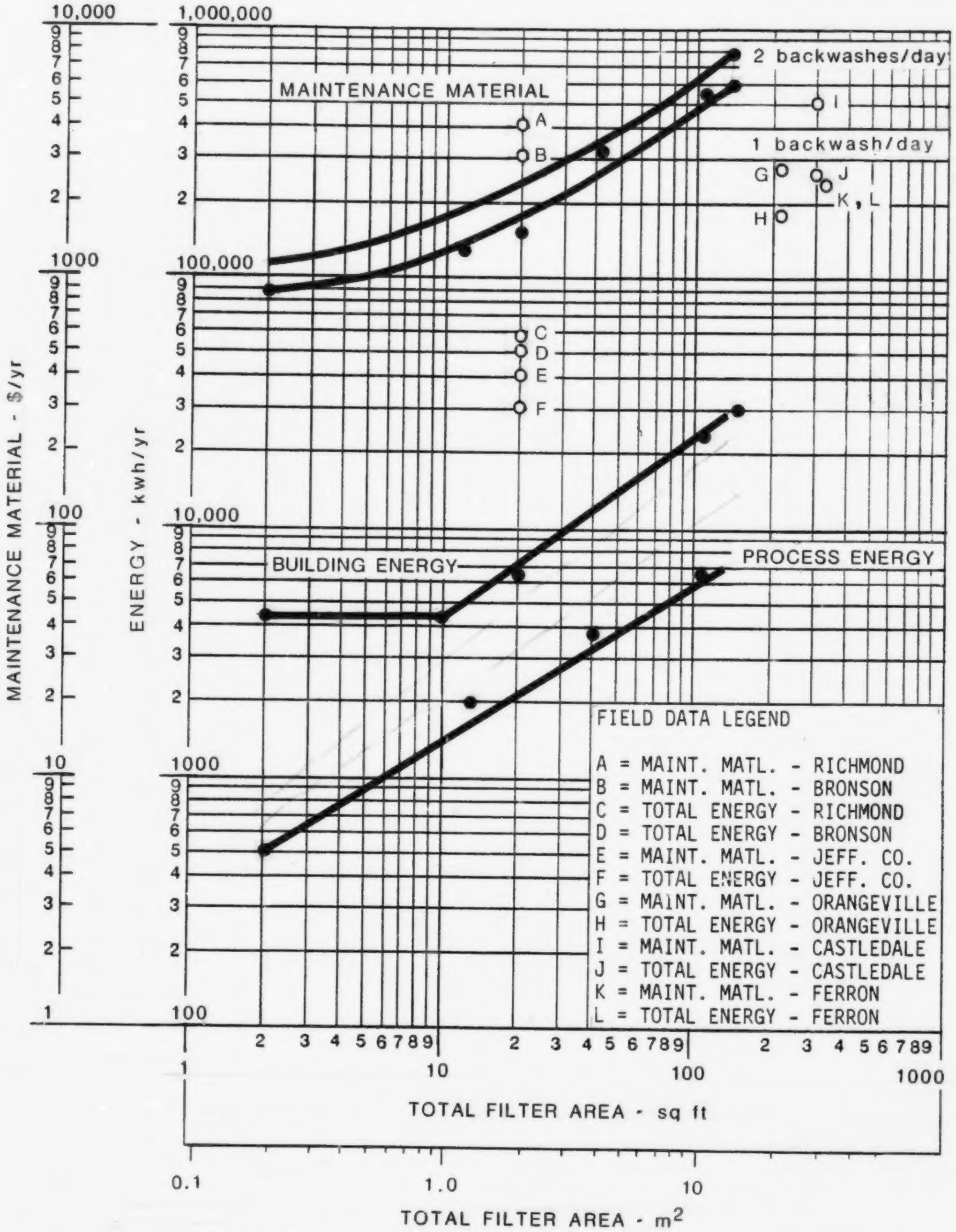


Figure 3. Operation and maintenance requirements for conventional package complete treatment plants - building energy, process energy and maintenance material.

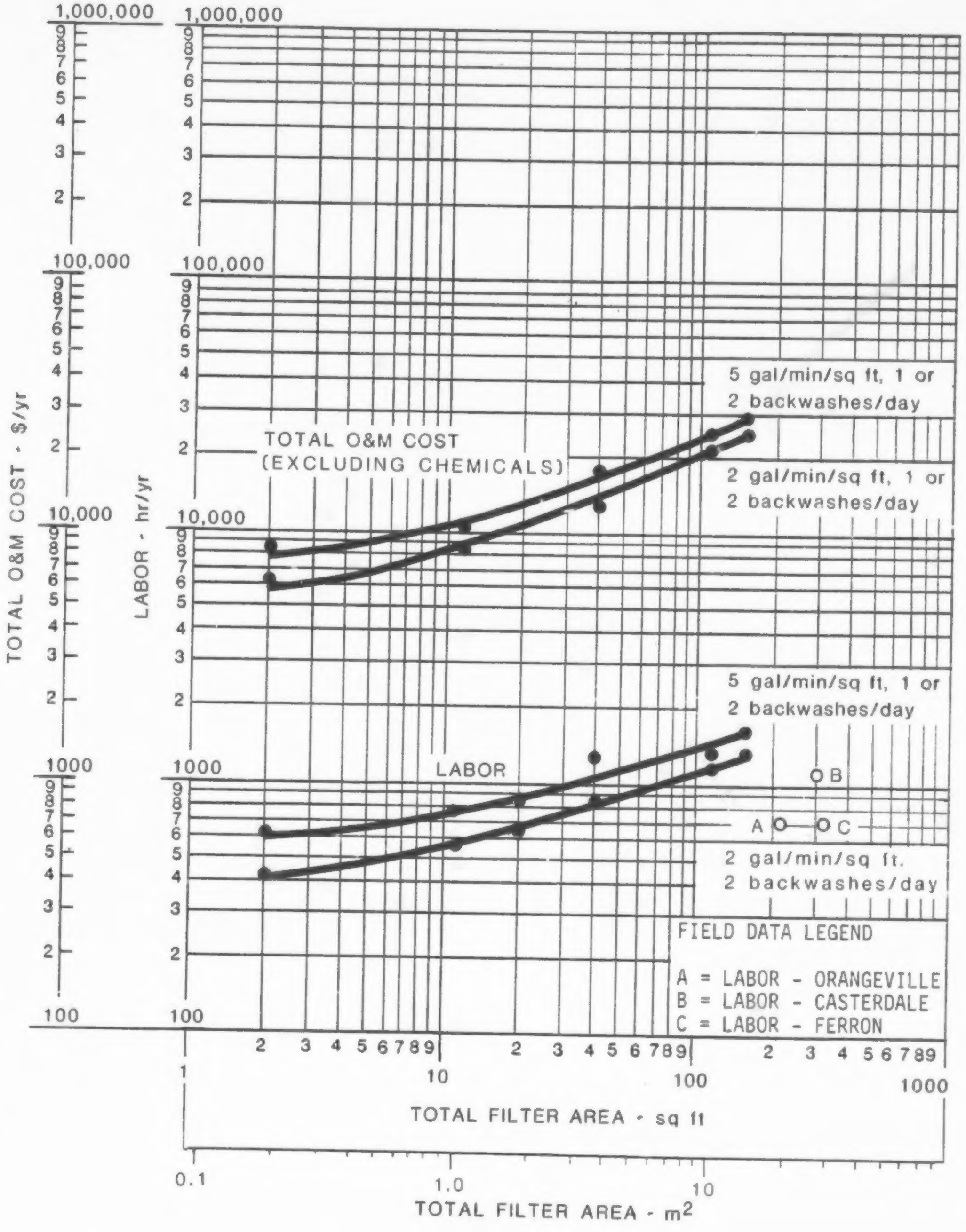


Figure 4. **Operation and maintenance requirements for conventional package complete treatment plants - labor and total O&M cost.**

CULLIGAN MULTI-TECH SYSTEM

Introduction

The Culligan Multi-Tech system is a package complete water treatment system which utilizes coagulant feed, pressurized downflow contact flocculation in a "coarse filter," and downflow pressure filtration using multi-media. The main application of this system is turbidity reduction; for moderate turbidity feed water, a product water with <1 NTU can be produced on a consistent basis with minimum operator attention. Removal of reduced iron and manganese is also possible, if chlorine, potassium permanganate, or some other oxidant is used prior to the Multi-Tech units. Activated carbon contactors may also be added to this system by the manufacturer, if there are taste and odor problems requiring correction, or other organics which must be removed.

The system consists of prewired, preplumbed, skid-mounted units, which include a cyclone separator for grit removal, alum and polymer feed units, a Depth Clarifier (coarse filter), a Depth Filter (multi-media filter), liquid chlorine feed unit, and controls. Raw water pumping is not included. The system is sized by the manufacturer using loading rates of 17.1 $m^3/m^2/h$ (7.0 gpm/sq ft) for both the Depth Clarifier and Depth Filter. When activated carbon treatment is included, a loading rate of 5.6-9.3 $m^3/m^2/h$ (2.3-3.8 gpm/sq ft) is used for the carbon columns.

Raw water feed pumps should supply a minimum inlet pressure of 1.41 kg/cm^2 (20 psi). Headloss is 0.35 kg/cm^2 (5 psi) in a clean state and 0.70-1.20 kg/cm^2 (10-17 psi) in a dirty state. Because the units operate under pressure, product water pumping to distribution or elevated storage is often not necessary if effluent pumps are properly selected.

Backwash is accomplished using raw water, eliminating the need for a backwash pump and backwash water storage. Influent water pressure is also used to operate diaphragm valves.

Impact of Raw Water Quality on Treatment Cost

Systems are rated by the manufacturer using a pre-established surface loading rate for the Depth Clarifier and Depth Filter. Therefore, in the majority of cases, increased turbidity will not influence capital cost. For excessively turbid waters, downgrading of system capacity may be recommended by the manufacturer after pilot testing, with a resultant increase in capital cost. If taste and odor is a problem, or if organic reduction is necessary, activated carbon contactors can be added, which will result in a capital cost increase.

Raw water quality will impact operation costs. As raw water turbidity increases, coagulant use increases and more frequent Depth Clarifier and Depth Filter backwashing is necessary. For units using activated carbon contactors, higher concentrations of adsorbable organics in the raw water will result in more rapid exhaustion of the carbon, and hence more frequent carbon replacement.

Construction Costs

Construction costs were developed using conceptual design criteria listed in Table 9. These costs are presented for the basic Multi-Tech system in Table 10 and the Multi-Tech system plus carbon contactors in Table 11. Costs are also presented graphically in Figure 5. The costs include cyclone separators, skid-mounted package Depth Clarifier and Filter units with media, skid-mounted alum, polymer, and chlorine feed systems, skid-mounted package carbon contactors with carbon, turbidimeter and wall-mounted control panels, influent and effluent water connections, sewer connection and an insulated, lighted building. Backwash can be initiated by a pressure differential switch, a time clock, or manually.

Operation and Maintenance Requirements and Costs

Process energy requirements are minimal, as electrical energy is required only for controls and chemical feed pumps and mixers. Energy for raw water pumping and product water pumping are not included. Building energy requirements are for heating, ventilation, and lighting and are based on an energy usage of 209.8 kwh/m^2/y (19.5 kwh/sq ft/yr).

Material requirements consist of replacement of pump seals, lubricants, replacement parts for pumps, valves, etc., instrumentation repair, and general maintenance supplies. The maintenance materials costs do not include the cost of treatment chemicals or replacement carbon, which are discussed in the following section.

Labor requirements were developed assuming that the treatment plant operates automatically. Operator attention is only necessary to prepare chemicals and/or replace premixed drums of chemicals for the automatic feeders, establish proper coagulant dosages, carry out routine monitoring, perform emergency repair, and perform necessary periodic maintenance. Labor cost associated with carbon removal and replacement is included in the cost of carbon.

The operation and maintenance requirements for the basic Multi-Tech system and the Multi-Tech system plus carbon are summarized in Tables 12 and 13, and are also shown in Figures 6 and 7. The cost of carbon replacement is not included in Table 13, but is discussed in the following section on chemical costs. The total operation and maintenance costs presented were developed assuming $0.07/kwh for electrical energy and $11/hour for labor.

Typical Chemical Requirements and Costs

Three chemicals are typically used with the Multi-Tech system; alum, polymer, and chlorine. Alum and polymer are used as coagulants and chlorine as a disinfectant. Carbon is also required for Multi-Tech systems which use carbon contactors.

The dosage of alum will depend upon water quality and to some extent will increase as the turbidity of the raw water increases. In general, dosages will range from 5 mg/L to 20 mg/L with a typical dosage being 10 mg/L.

TABLE 9. CONCEPTUAL DESIGNS FOR MULTI-TECH PACKAGE COMPLETE TREATMENT

Plant Capacity, gpd	Multi-Tech Clarifier and Filter			Carbon Contactors			Housing, sq ft	
	No.	Diameter, ft	Loading, gpm/sq ft	No.	Diameter, ft	Loading, gpm/sq ft	Multi-Tech	Multi-Tech and Carbon
65,000	3	1.67	6.85	3	2	4.77	360	500
140,000	3	2.5	6.79	3	3	4.72	520	700
370,000	3	4	6.90	3	5	4.41	900	1,300
590,000	3	5	6.79	3	6	4.72	1,300	1,900
1,100,000	3	7	6.93	3	8	5.31	1,900	2,700

Notes:
1. Number, sizing and loadings are the same for both the depth clarifier and the depth filter.
2. Housing has a height of 14 ft.
3. Carbon depth in the contactors is 5 ft.

TABLE 10. CONSTRUCTION COST SUMMARY FOR MULTI-TECH SYSTEM

Cost Category	Plant Capacity, gpd 65,000	 140,000	 370,000	 590,000	 1,100,00
Excavation and Sitework	$ 4,000	$ 4,800	$ 5,600	$ 7,000	$ 11,800
Manufactured Equipment	53,800	64,200	105,800	135,500	211,800
Concrete	1,100	1,600	2,700	3,900	5,700
Labor, Installation	16,100	19,300	31,700	40,700	63,500
Pipe and Valves	4,300	5,100	8,500	10,800	17,000
Electrical, Instrumentation	7,500	9,000	14,800	19,000	29,700
Housing	24,500	30,200	43,200	49,400	58,900
Subtotal	111,300	134,200	212,300	266,300	398,400
Design Contingencies	16,700	20,100	31,900	39,900	59,800
Total	$128,000	$154,300	$244,200	$306,200	$458,200

TABLE 11. CONSTRUCTION COST SUMMARY FOR MULTI-TECH SYSTEM PLUS CARBON

Cost Category	Plant Capacity, gpd 65,000	 140,000	 370,000	 590,000	 1,100,000
Excavation and Sitework	$ 4,800	$ 5,200	$ 7,000	$ 11,800	$ 16,700
Manufactured Equipment	61,100	78,100	138,400	177,500	284,200
Concrete	1,500	2,100	3,900	5,700	8,100
Labor, Installation	18,300	23,400	41,500	53,300	85,300
Pipe and Valves	4,900	6,300	11,100	14,200	22,700
Electrical, Instrumentation	8,600	10,900	19,400	25,000	39,900
Housing	29,000	36,400	49,400	58,900	72,900
Subtotal	128,200	162,400	270,700	346,400	529,800
Design Contingencies	19,200	24,400	40,600	52,000	79,500
Total	$147,400	$186,800	$311,300	$398,400	$609,300

TABLE 12. OPERATION AND MAINTENANCE SUMMARY FOR MULTI-TECH SYSTEM

Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
65,000	7,000	1,500	8,500	1,400	590	8,500
140,000	10,100	2,000	12,100	2,200	640	10,100
370,000	17,600	4,000	21,600	5,700	890	17,000
590,000	25,400	4,500	29,900	8,400	970	21,200
1,100,000	37,100	5,300	42,400	13,700	1,260	30,500

Note: Total cost is based on $0.07 kwh of electrical energy and $11.00/hour of labor.

TABLE 13. OPERATION AND MAINTENANCE SUMMARY FOR MULTI-TECH SYSTEM PLUS CARBON

Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
65,000	9,800	1,500	11,300	1,600	650	9,600
140,000	13,700	2,000	15,700	2,500	700	11,300
370,000	25,400	4,000	29,400	6,000	980	18,900
590,000	37,100	4,500	41,600	9,800	1,070	24,500
1,100,000	52,700	5,300	58,000	16,000	1,390	35,400

Notes:
1. Carbon replacement costs are not included.
2. Total cost is based on $0.07/kwh of electrical energy and $11/hour of labor.

Polymers may be used as primary coagulants, secondary coagulants, or as flocculants. The Multi-Tech system uses a moderate molecular weight polymer as a secondary coagulant. In some instances, alum may not be used and the polymer is then used as the primary coagulant. Dosages range from less than 0.25 mg/L up to 1 mg/L. A typical dosage would be 0.5 mg/L.

Chlorine dosages will depend upon the chlorine demand of the water and the desired residual. Residuals may range from 0.5 mg/L up to 2 mg/L depending upon local conditions and requirements. A typical dosage would be 3 mg/L.

Table 14 presents typical alum, polymer, and chlorine requirements and costs applicable to both the Multi-Tech system and the Multi-Tech system plus carbon. The costs are based upon the following dosages and unit costs.

	Dosage	Unit Cost
Alum	10 mg/L	$0.15/lb
Polymer	0.5 mg/L	$3.00/lb
Chlorine	3 mg/L	$0.37/lb

TABLE 14. TYPICAL CHEMICAL COSTS FOR MULTI-TECH SYSTEM

Plant Flow Rate, gpd	Alum		Polymer		Chlorine		Total Chemical Cost, $/yr
	Use lb/yr	Cost $/yr	Use lb/yr	Cost $/yr	Use lb/yr	Cost $/yr	
65,000	2,000	300	100	300	590	220	820
140,000	4,300	640	210	640	1,300	480	1,760
370,000	11,300	1,700	560	1,700	3,400	1,300	4,700
590,000	18,000	2,700	900	2,700	5,400	2,000	7,400
1,100,000	33,500	5,000	1,700	5,000	10,000	3,700	13,700

The cost of replacement carbon depends upon the replacement frequency. Table 15 presents carbon costs for replacement frequencies of 3, 6, 12, and 18 months. A formula is also shown in Table 15 for calculation of carbon costs at other replacement frequencies.

TABLE 15. TYPICAL CARBON REPLACEMENT COSTS FOR MULTI-TECH SYSTEM PLUS CARBON

Plant Flow Rate, gpd	Contactor Volume, cu ft	Frequency of Carbon Replacement			
		3 Months	6 Months	12 Months	18 Months
65,000	96.2	$ 12,000/yr	$ 6,000/yr	$ 3,000/yr	$ 2,000/yr
140,000	19.7	24,600	12,300	6,200	4,100
370,000	504	62,900	31,500	15,700	10,500
590,000	577	72,000	36,000	18,000	12,000
1,100,000	1005	$125,400/yr	$62,700/yr	$31,400/yr	$20,900/yr

Notes:
1. Carbon density = 26 lb/cu ft.
2. Carbon cost (installed) is $1.20/lb.
3. For calculation of annual cost at other replacement frequencies, use the following formula:

$$\$/yr = \frac{(\text{cu ft of Carbon})(26\ \text{lb/cu ft})(\$1.20/\text{lb})(12\ \text{mo/yr})}{(\text{Carbon Replacement Frequency in Months})}$$

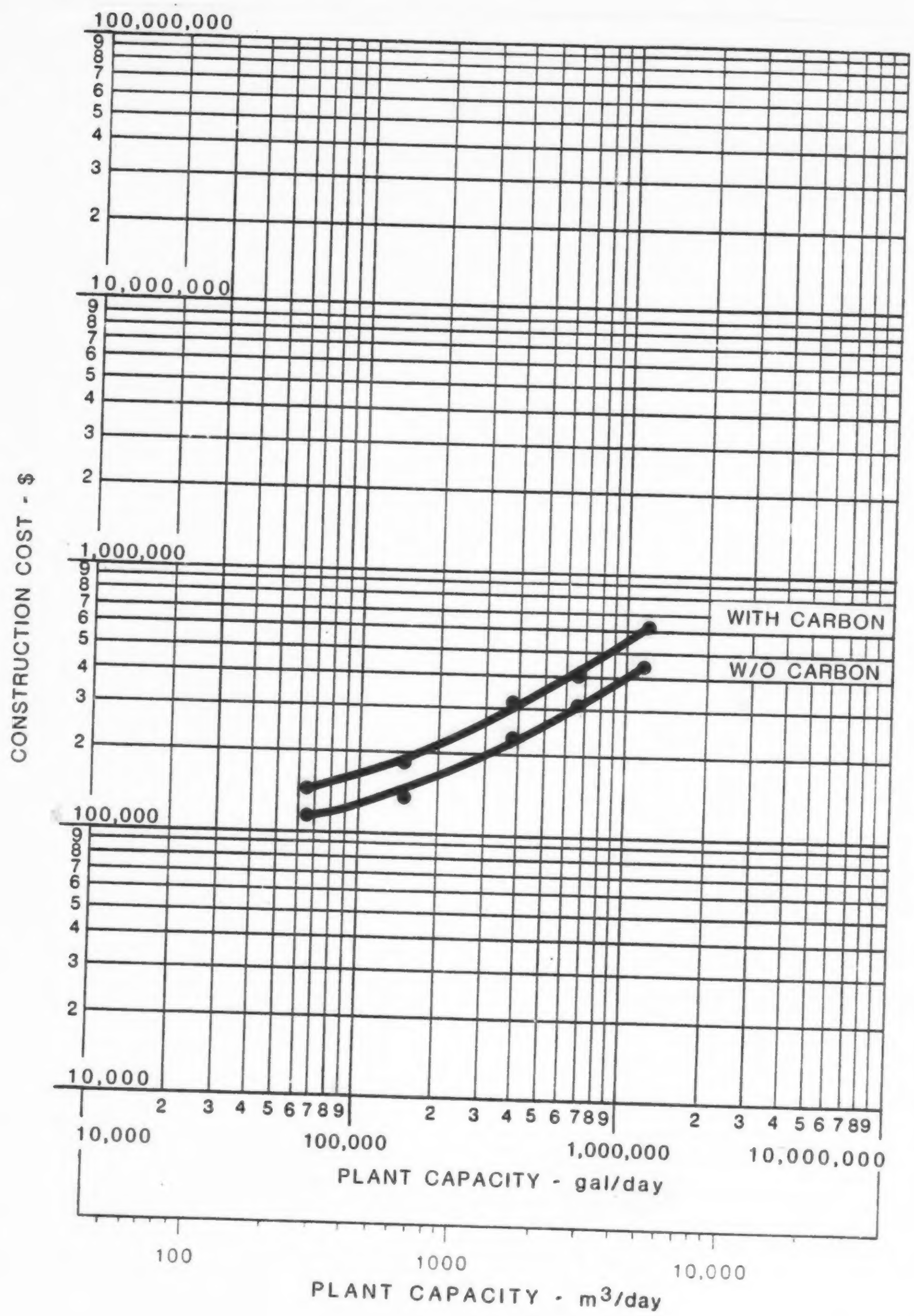


Figure 5. **Construction cost for Culligan Multi-Tech System.**

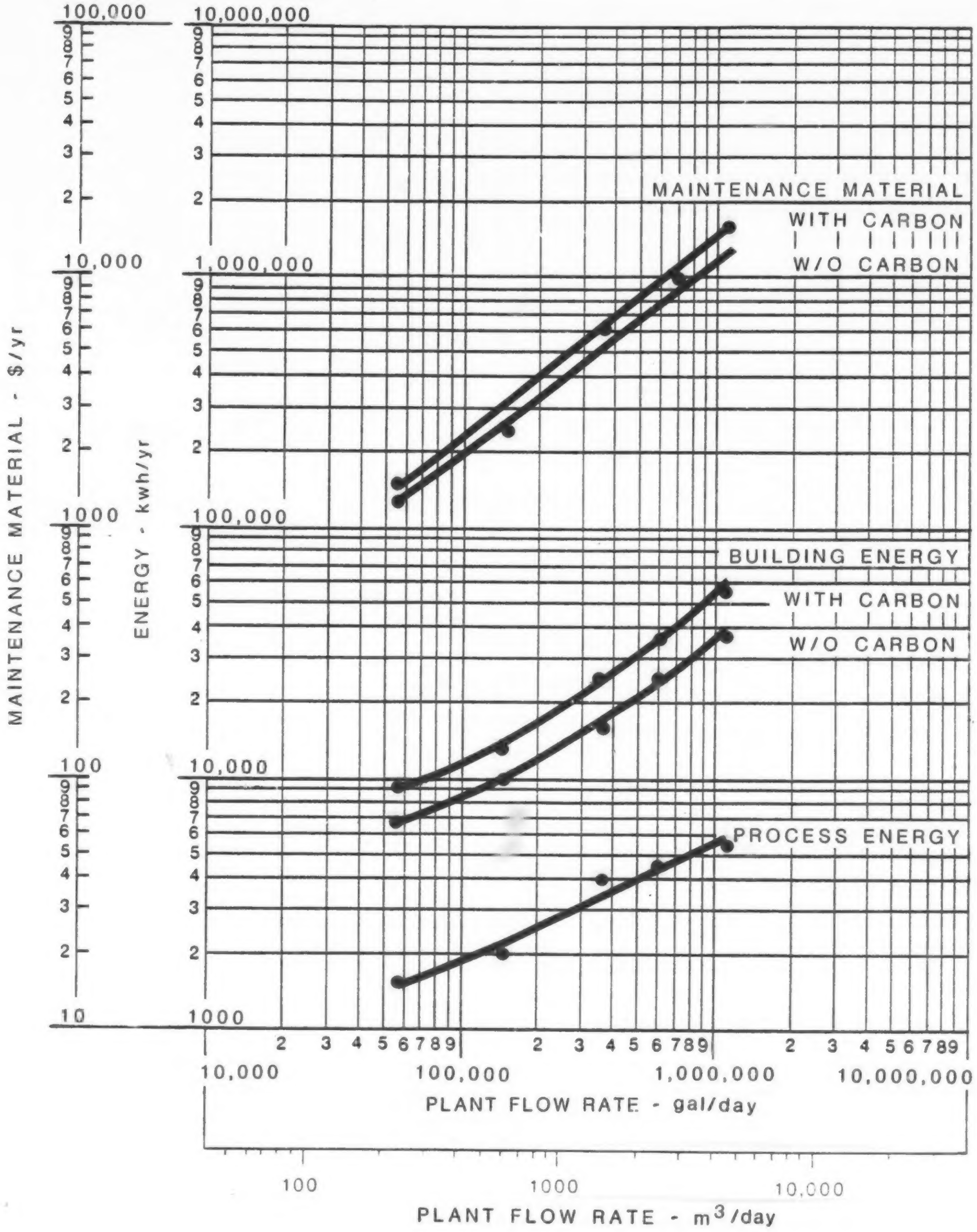


Figure 6. Operation and maintenance requirements for Culligan Multi-Tech System - building energy, process energy, and maintenance material.

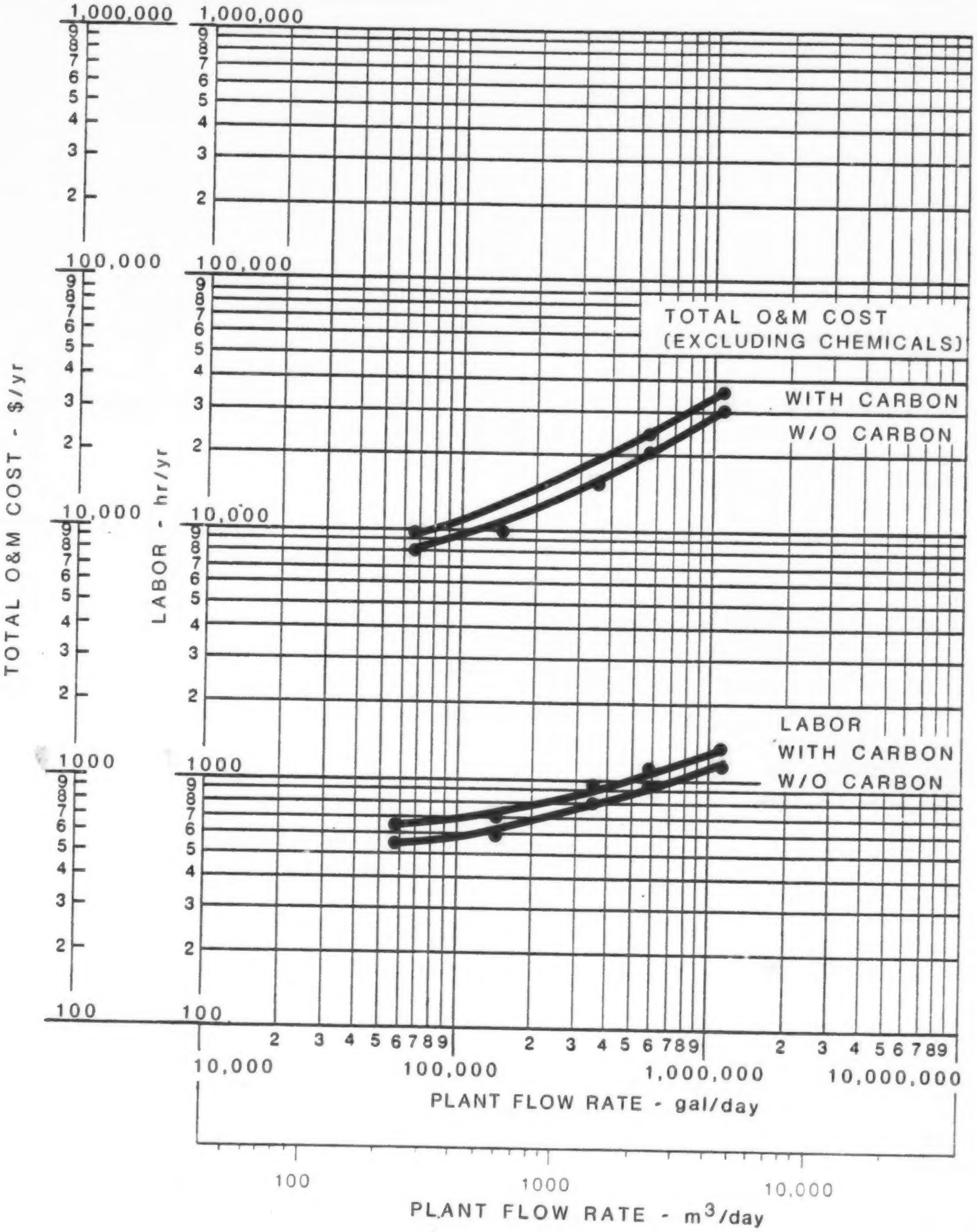


Figure 7. Operation and maintenance requirements for Culligan Multi-Tech System - labor and total O&M cost.

NEPTUNE MICROFLOC TRIDENT SYSTEM

Introduction

The Neptune Microfloc Trident System is a package complete treatment system which uses an upflow Adsorption Clarifier followed by mixed media filtration. Both units are contained in a single steel tank, with a submerged broad crested weir separating the units. The Trident System is designed to operate at a constant, but adjustable, flow rate. Water level in the plant clearwell can be used as an on-off signal to the treatment system.

The adsorption clarifier uses a packed bed of buoyant adsorption media, with a media retainer used to prevent media loss during the upflow backwash cycle. When a chemically coagulated water is introduced into the adsorption clarifier, the coagulated solids are removed on the media surface, with removals being enhanced by contact with previously removed solids. Adsorption clarifier loading rates are typically from 24.4 to 36.6 $m^3/m^2/h$ (10 to 15 gpm/sq ft). Turbidity removals up to 95% in the clarifier are claimed to be possible.

Excess solids must be flushed from the adsorption clarifier one or more times during a filter run. Flushing can be initiated by a time clock, or by headloss in the clarifier. Flushing consists of two independent steps, diffused air addition and hydraulic flushing of the scoured solids from the clarifier. First, diffused air is introduced into the bottom of the adsorption clarifier, causing expansion and scrubbing of the media. Secondly, influent water is introduced to the bottom of the clarifier, flushing the solids out the top of the clarifier. A typical frequency for clarifier flushing is every 4-8 hours, and the duration of the flushing cycle is 2-5 minutes. During clarifier flushing, the filter effluent valve is closed, thus preventing carry over of flushed solids onto the filter.

Filtration is accomplished using mixed media at a filtration rate of 12.2 to 18.3 $m^3/m^2/h$ (5 to 7.5 gpm/sq ft). A constant water level in the filter is maintained by a float operated level transmitter above the filter which controls the opening of the filter effluent valve. Filter backwash is at a rate of 36.6 $m^3/m^2/h$ (15 gpm/sq ft) at 15.6°C (60°F), and the rate must be varied at other water temperatures. Surface wash at a rate of 1.22 to 2.44 $m^3/m^2/h$ (0.5 to 1 gpm/sq ft) is also used during filter backwash. Flushing of the clarifier is always performed during filter backwash.

Coagulant control is accomplished using a microprocessor. Filter effluent turbidity is the input signal for the microprocessor. The microprocessor compares this reading to the plant set-point for effluent turbidity, and adjusts alum and/or polymer dosage accordingly. A key advantage of the microprocessor control is that chemical dosage is optimized, resulting in a savings in chemical costs. The microprocessor can also receive input signals for flow and pH, and adjust dosages of coagulant chemicals or chemicals for pH control in response. A programmable controller is used to control all automatic valves, and to initiate and complete clarifier flushing and filter backwashing.

Applications of the Trident System include the removal of turbidity, color, iron and manganese, and taste and odor. Alum, with polymer as a filter aid, is typically used for turbidity and color removal. Removal of iron and manganese requires oxidation with chlorine or potassium permanganate, and polymer as the coagulant. Lime or soda ash addition may also be necessary to elevate pH and enhance removal of iron and manganese. Lime and soda ash additions may also be necessary in some plants for supplementing alkalinity. Powdered activated carbon can be used for removal of taste and odor compounds.

Impact of Raw Water Quality on Treatment Cost

Within reasonable limits, raw water turbidity will not affect capital cost. Test results at different locations have shown that raw water turbidities of 30 NTU can be reduced to as low as 0.1 NTU.

Conversely, operating cost for chemicals is strongly influenced by raw water turbidity. Increased raw water turbidity or color requires higher coagulant dosages. Similarly, increased iron and manganese concentrations require higher coagulant dosages.

Construction Costs

The Trident System is prefabricated at the factory, and is contained in one or more free standing units. Conceptual designs for units included in the cost estimates are shown in Table 16. The smallest size available can treat flows up to 953.8 m^3/d (252,000 gpd) using a single unit. Lower flows could also be treated by this unit, but this may become uneconomic at low flow rates.

TABLE 16. CONCEPTUAL DESIGNS FOR NEPTUNE MICROFLOC TRIDENT SYSTEM

Plant Capacity, gpd	Adsorption Clarifier		Filters		Housing	
	Total Area, sq ft	Loading, gpm/sq ft	Total Area, sq ft	Loading, gpm/sq ft	LxWxH, ft	Area, sq ft
252,000	17.5	10	35	5	30x21x14	630
504,000	35	10	70	5	30x30x14	900
1,008,000	70	10	140	5	35x35x14	1,225

Note: The 252,000 gpd plant capacity system uses a single treatment unit; parallel treatment units are used for the two larger sizes.

In addition to the steel tankage, alum and polymer solution tanks and metering pumps are included. Metering pumps are SCR controlled, variable speed, to respond to the microprocessor output signal. Coagulant feed is into the raw water line leading to the Trident Systems. The microprocessor which controls coagulant feed is included, as is the programmer which controls automatic process control valves. Treatment units are completely housed, and housing dimensions are included in Table 16. Necessary piping and valves and all piping within the building are included in the costs. The costs include backwash pumps and a positive displacement air compressor to supply air for clarifier flushing.

The cost estimates do not include raw water pumps, clearwell storage, or finished water pumping. Construction costs are presented in Figure 8 and in Table 17.

TABLE 17. CONSTRUCTION COST SUMMARY FOR NEPTUNE MICROFLOC TRIDENT SYSTEM

	Plant Capacity, gpd		
Cost Category	252,000	504,000	1,008,000
Excavation and Sitework	$ 5,100	$ 5,600	$ 7,000
Manufactured Equipment	73,500	115,500	141,800
Concrete	1,900	2,700	3,700
Labor, Installation	22,100	34,700	42,500
Pipe and Valves	8,800	18,500	22,700
Electrical, Instrumentation	10,300	16,200	19,900
Housing	33,400	41,400	49,000
Subtotal	155,100	234,600	286,600
Design Contingencies	23,300	35,200	43,000
Total	$178,400	$269,800	$329,600

Operation and Maintenance Requirements and Costs

Process energy requirements are for chemical mixers, chemical feed pumps, compressed air for the adsorption clarifier flushing operation and for the control system, and filter backwash and surface wash.

Chemical feed pumps were considered to operate 24 hours/day, while chemical mixers are only operated for 15 to 30 minutes following preparation of a new solution. Backwash was considered to last for eight minutes at a rate of 36.6 $m^3/m^2/h$ (15 gpm/sq ft) and a 13.7 m (45 ft) head. Filter surface wash units were rated at 3.5 kg/cm^2 (50 psi) and were assumed to operate for 4 minutes per backwash. Process energy requirements were calculated for both one and two backwashes per day at a filtration rate of 12.2 $m/^3/m^2/h$ (5 gpm/sq ft).

Building energy is required for heating, ventilation and lighting, with the latter assumed to be 3 hours/day. Building energy requirements are based upon 209.8 $kwh/m^2/y$ (19.5 kwh/sq ft/yr) and the building areas shown in Table 16.

Maintenance materials are for replacement of mechanical and electrical components which either wear out or break down during normal operations.

Chemical costs are not included in maintenance material costs, and must be added separately. A guide to typical chemical costs is included in the following section.

Labor requirements are for both maintenance and operation, with the majority of labor being required for operation. The operator is required, on a daily basis, to maintain chemical storage tanks filled with chemicals in the proper concentration to assure that satisfactory water quality is being produced, and to perform other routine laboratory testing as required. Some maintenance items may also be required on a daily basis, as will general housekeeping.

Operation and maintenance requirements and costs are summarized in Table 18 and are also shown in Figures 9 and 10.

TABLE 18. OPERATION AND MAINTENANCE SUMMARY FOR NEPTUNE MICROFLOC TRIDENT SYSTEM

Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
One Filter Backwash/Day						
252,000	12,300	1,100	13,400	2,500	640	10,500
504,000	17,600	1,500	19,100	4,000	1,020	16,600
1,008,000	23,900	2,300	26,200	4,900	1,220	20,200
Two Filter Backwashes/Day						
252,000	12,300	1,400	13,700	3,100	667	11,400
504,000	17,600	2,000	19,600	5,000	1,053	18,000
1,008,000	23,900	3,200	27,100	6,200	1,258	21,900

Note: Total cost is based on $0.07/kwh of electrical energy and $11/hour of labor. Twenty-four hour/day operation is assumed.

Typical Chemical Requirements and Costs

Table 19 presents typical costs for turbidity reduction, iron removal, and color removal applications. Requirements and costs presented in this table are based on the following dosages:

Turbidity Reduction
    Alum - 10 mg/L
    Polymer - 0.2 mg/L

Iron Removal
- Polymer - 0.13 mg/L
- Chlorine - 0.6 mg/L

Color Removal
- Alum - 30 mg/L
- Polymer - 0.01 mg/L

These are typical dosages based upon pilot testing conducted by the manufacturer, and they should be expected to vary between different water supplies. Satisfactory product water quality could also be obtained at both higher and lower dosages than these although there would be resultant changes in the length of filter run and the frequency of clarifier flushing. Thus, the optimum chemical dosage must be determined for each individual water supply, and this determination must consider length of filter run and frequency of clarifier flushing, as well as chemical cost.

Chemical costs used in Table 19 were \$0.29/kg (\$0.13/lb) for alum, \$6.60/kg (\$3.00/lb) for polymer, and \$0.81/kg (\$0.37/lb) for chlorine. Costs will vary depending upon the plant location and the quantity of chemicals purchased in a given time period.

TABLE 19. TYPICAL CHEMICAL COSTS FOR NEPTUNE MICROFLOC TRIDENT SYSTEM

Plant Flow Rate, gpd	Alum		Polymer		Chlorine		Total Chemical Cost, $/yr
	Use lb/yr	Cost $/yr	Use lb/yr	Cost $/yr	Use lb/yr	Cost $/yr	
Turbidity Reduction Applications							
252,000	7,670	1,000	150	500	--	--	1,500
504,000	15,340	2,000	310	900	--	--	2,900
1,008,000	30,690	4,000	610	1,800	--	--	5,800
Iron Removal Applications							
252,000	--	--	100	300	460	170	470
504,000	--	--	200	600	920	340	940
1,008,000	--	--	400	1,200	1,840	700	1,900
Color Removal Applications							
252,000	23,020	3,000	8	25	--	--	3,000
504,000	46,030	6,000	16	50	--	--	6,000
1,008,000	92,060	12,000	31	100	--	--	12,100

Note: Costs for chemicals are: Alum - \$0.13/lb; Polymer - \$3.00/lb; and Chlorine - \$0.37/lb.

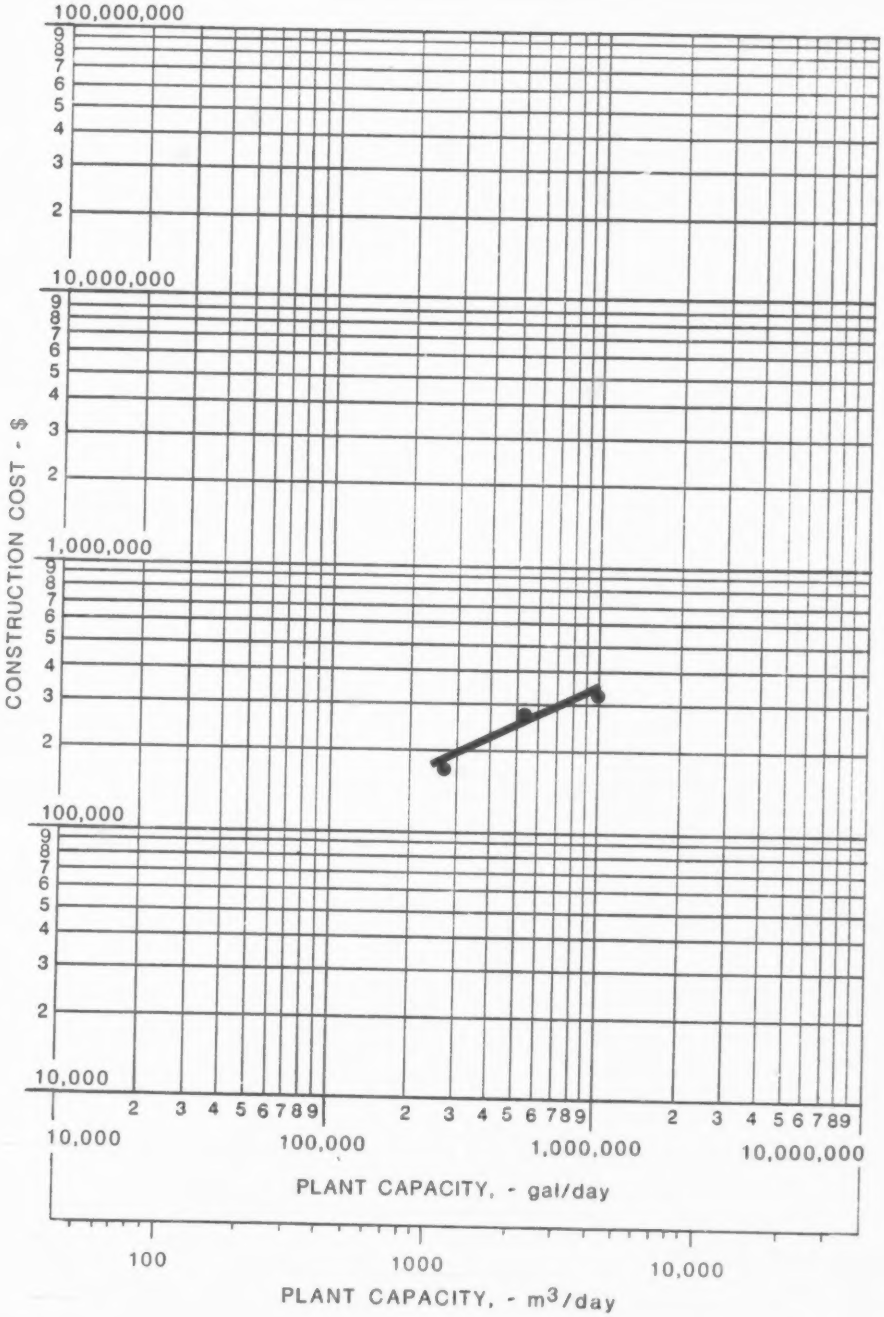


Figure 8. **Construction cost for Neptune Microfloc Trident System.**

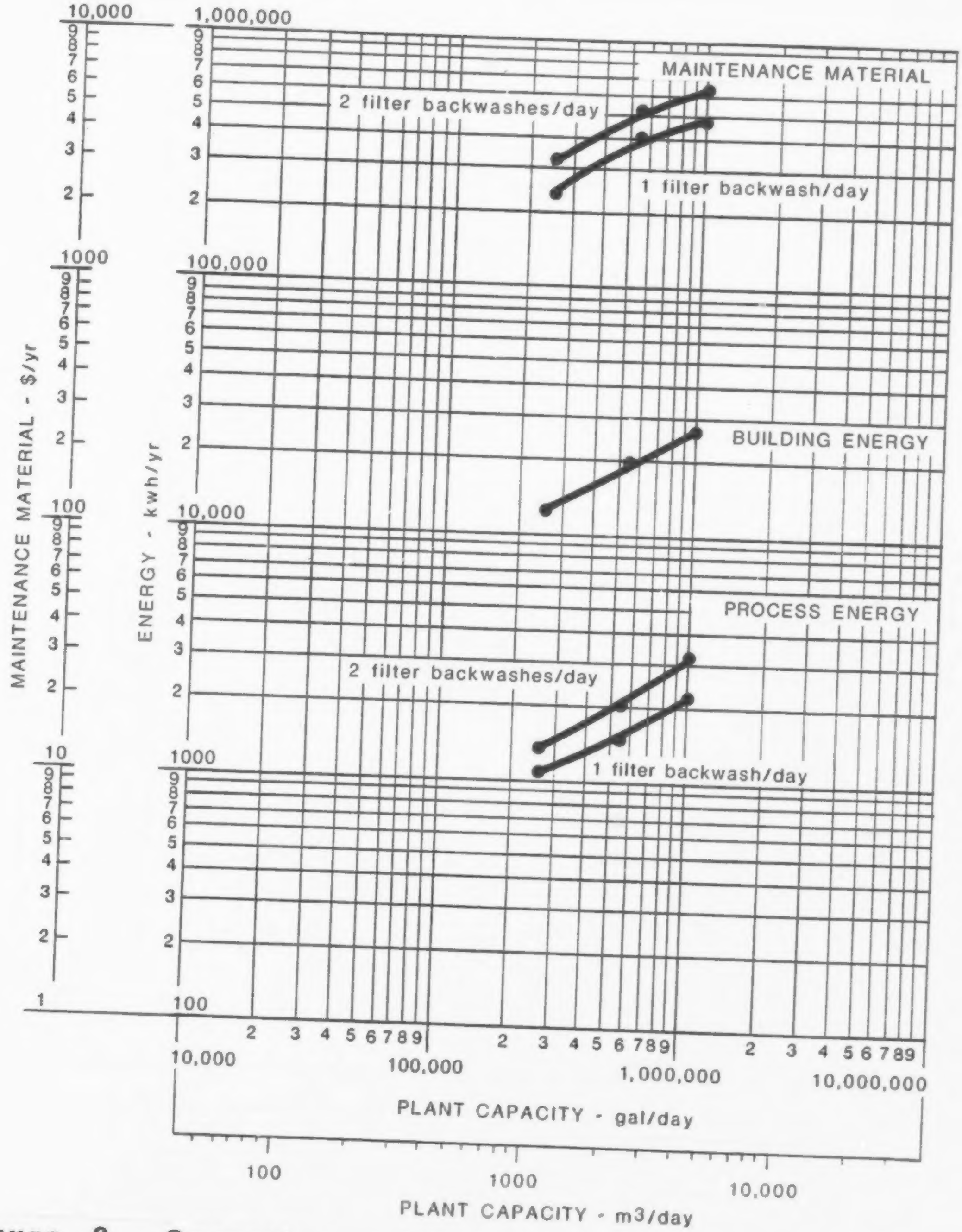


Figure 9. **Operation and maintenance requirements for Neptune Microfloc Trident System - building energy, process energy, and maintenance material.**

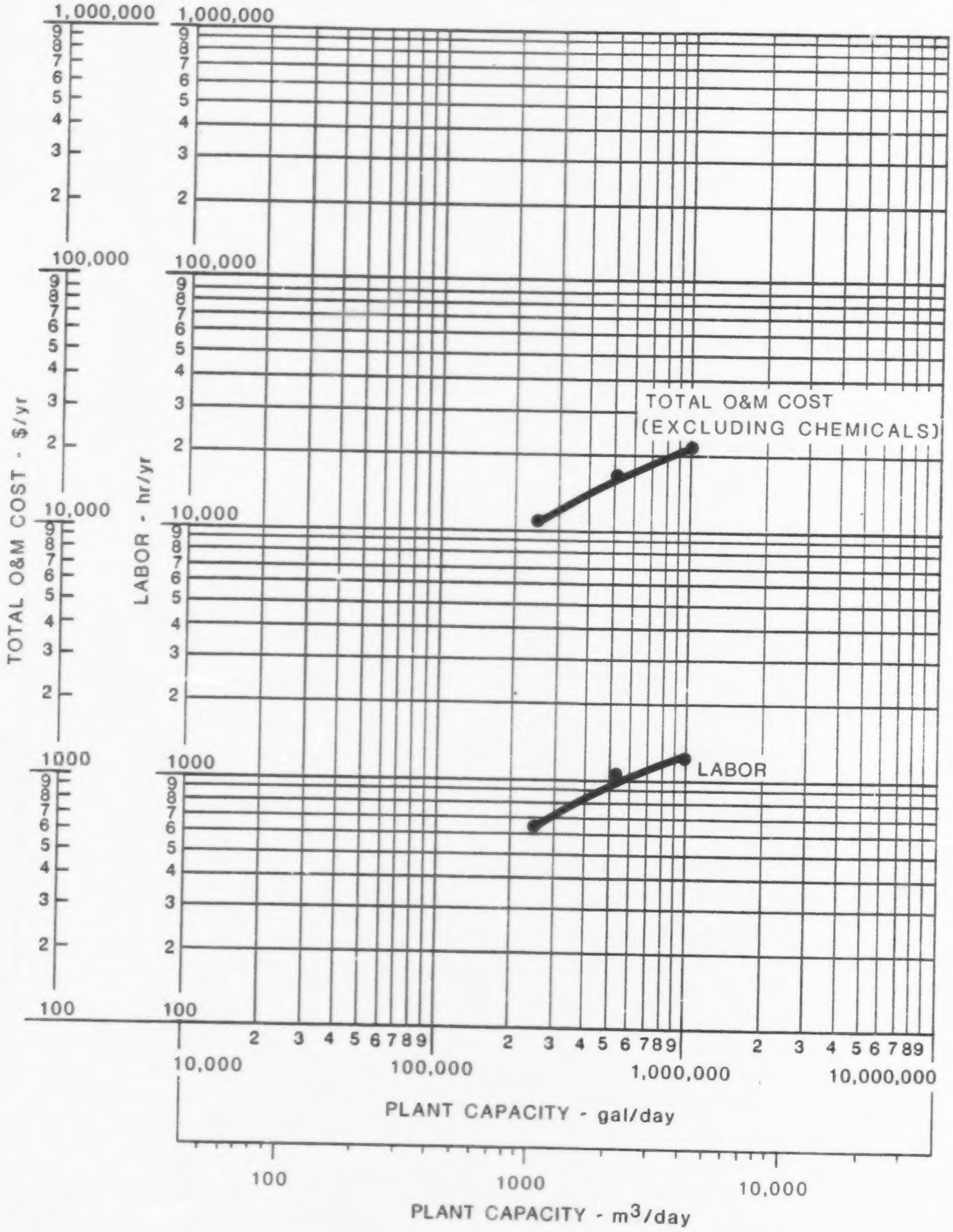


Figure 10. Operation and maintenance requirements for Neptune Microfloc Trident System - labor and total O&M cost.

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PACKAGE LIME SOFTENING

Introduction

The lime softening process uses lime or lime and soda ash (sodium carbonate) to precipitate calcium and magnesium hardness. Several process modifications are possible, depending upon the form of hardness present in the raw water, and the final hardness desired in the product water. The following sections discuss the chemical reactions involved in lime and lime-soda softening, as well as process modifications and their application.

Chemical Reactions--

The chemical reactions which occur during softening are shown and discussed following:

Carbon Dioxide Reactions--

Reaction 1 - $CO_2 + Ca(OH)_2 \rightarrow \underline{CaCO_3} + H_2O$

Reaction 1 - Lime reacts with carbon dioxide. This is the first reaction, and it occurs before the pH can be raised to a level at which other reactions occur. Although carbon dioxide is not hardness, this reaction must be considered in calculating lime dosage and sludge generation. If carbon dioxide is present in high concentrations, generally above 10 mg/L, alternative methods of carbon dioxide removal, such as aeration, should be considered.

Carbonate Hardness Reactions With Lime--

Reaction 2 - $Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow \underline{2CaCO_3} + 2H_2O$

Reaction 3 - $Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow \underline{CaCO_3} + MgCO_3 + 2H_2O$

Reaction 4 - $MgCO_3 + Ca(OH)_2 \rightarrow \underline{Mg(OH)_2} + \underline{CaCO_3}$

Reaction 2 - Lime reacts with carbonate hardness expressed as calcium bicarbonate. One mole (gram molecular weight) of lime is required per mole of calcium removed.

Reactions 3 and 4 - Magnesium bicarbonate hardness is converted to magnesium carbonate in Reaction 3, then precipitated as magnesium hydroxide in Reaction 4. Two moles of lime are required per mole of magnesium removed. The second reaction requires excess lime (about 35 mg/L) to raise pH to the required level of 10.8 or above.

Noncarbonate Hardness Reactions With Lime and Soda Ash--

Reaction 5 - $MgSO_4 + Ca(OH)_2 \rightarrow \underline{Mg(OH)_2} + CaSO_4$

Reaction 6 - $CaSO_4 + Na_2CO_3 \rightarrow \underline{CaCO_3} + Na_2SO_4$

Reactions 5 and 6 - To remove noncarbonate hardness, both lime and soda ash are required. One mole of both lime and soda ash are required per mole of noncarbonate hardness removed. In Reaction 5, calcium noncarbonate hardness is produced. There is no change in hardness in Reaction 5. Soda ash is then used to precipitate this noncarbonate hardness, as shown in Reaction 6.

Recarbonation Reactions--

Reaction 7 - $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

Reaction 8 - $CaCO_3 + CO_2 + H_2O = Ca(HCO_3)_2$

Reactions 7 and 8 - In Reaction 7 carbon dioxide converts excess calcium hydroxide and in Reaction 8, further carbon dioxide addition drops the pH below 9.5 and converts calcium carbonate to bicarbonate.

Process Modifications--

Single Stage Treatment With Recarbonation--Single stage treatment followed by recarbonation is used for the majority of applications.[1] This technique can be used for removal of calcium and magnesium carbonate hardness, as well as noncarbonate hardness. The types of chemicals which are used and their dosages impact the constituents removed and the degree of removal.

When the majority of the hardness is carbonate hardness, and the magnesium concentration is low, lime alone is used in stoichiometric quantities for removal of the calcium carbonate hardness (Reaction 2). To remove magnesium carbonate hardness, lime $Ca(OH)_2$ must be added to about 35 mg/L above stoichiometric amounts to raise pH to 10.8, which allows magnesium precipitation as magnesium hydroxide (Reactions 3 and 4). When soda ash is used in conjunction with excess lime, noncarbonate hardness is also precipitated (Reactions 5 and 6). Recarbonation lowers pH and converts any remaining lime or insoluble calcium carbonate to soluble bicarbonate (Reactions 7 and 8). Hardness levels as low as 40-50 mg/L are possible with single stage treatment.

Two Stage Softening and Recarbonation--Two stage treatment uses excess lime in the first stage (rapid mix, flocculation, and settling), first stage recarbonation, a second stage (rapid mix, flocculation, and settling) with soda ash addition, and second stage recarbonation.[2] In the first stage recarbonation, only enough carbon dioxide is added for Reaction 7 to occur, and the insoluble calcium carbonate is precipitated. In the second stage, soda ash is added, and noncarbonate hardness is removed according to Reaction 6. The second stage recarbonation follows Reaction 8. Two stage softening is used for the removal of maximum quantities of magnesium.

Split-Treatment With Recarbonation--In split treatment, a portion of the flow is treated with excess lime, and the remaining flow is bypassed.[2,3] The treated and untreated flows are then recombined and in many cases recarbonation is not necessary. If removal of noncarbonate hardness is necessary, the combined flow can be treated with a second stage of soda ash softening. Split-treatment is operated at pH >10.8, and is most applicable for waters with a high magnesium content, and in situations where only a portion of the hardness must be removed. The advantages of split treatment include more efficient use of lime than in conventional softening, and the potential for elimination of recarbonation.

Impact of Raw Water Quality on Treatment Cost

The impact of raw water quality on lime system treatment costs is significant. Chemical requirements are dictated by the presence and concentration of carbon dioxide, calcium and magnesium carbonate hardness and calcium and magnesium noncarbonate hardness. Also, the desired level of effluent hardness dictates the chemical requirements.

In addition to influencing chemical requirements, the quality of the raw water also dictates plant facilities. Facilities which may operate in a split treatment mode may not require recarbonation, and facilities which employ the low lime softening process will typically not employ any mode of recarbonation. To determine required chemical dosages, laboratory tests on the quantity and type of hardness in the raw water are necessary. Calculations can then be performed utilizing the equations presented above and the desired level of effluent hardness to determine chemical dosing requirements. Fine tuning of chemical dosing is accomplished under operation by testing final hardness, pH, and stability of the product water.

Construction Costs

Construction costs are for modular treatment facilities which are completely housed. Construction cost data is for two different treatment configurations: single stage with lime and soda ash addition, and two stage with lime used in the first stage and soda ash in the second. Treatment consists of chemical addition, rapid mix, slow mix, and upflow solids contact clarification.

For pH depression following treatment, sulfuric acid with a soda ash buffer is used for the two smaller plant sizes. For the 1,828 m^3/d (430,000 gallon/day) plant, gaseous carbon dioxide purchased in cylinders is used for recarbonation, and for the two larger plant sizes, liquid carbon dioxide delivered in bulk is used for recarbonation. Recarbonation is accomplished in a sixteen foot deep concrete basin using fine bubble diffusion.

Hydrated lime purchased in bags was used for the three smaller plants, with quicklime delivered in bulk and on-site slaking used for the two larger sizes. Soda ash purchased in bags would be used for smaller plant sizes, and bulk delivery would be used for larger sizes.

A typical layout for a single stage lime softening plant is shown in Figure 11. Construction costs are tabulated in Tables 20 and 21 and are also presented in Figure 12.

TABLE 20. CONSTRUCTION COST SUMMARY FOR PACKAGE LIME SOFTENING - SINGLE STAGE

Cost Category	Plant Capacity, gpd 15,000	150,000	430,000	750,000	1,000,000
Excavation & Site Work	$ 3,500	$ 5,800	$ 6,700	$ 8,400	$ 9,800
Manufactured Equipment	33,200	49,800	66,300	86,200	103,800
Concrete	1,100	2,500	3,200	5,900	7,000
Labor, Installation	14,000	18,200	28,000	36,400	43,800
Pipe & Valves	5,200	10,400	14,100	16,700	45,900
Electrical, Instrumentation	8,500	12,200	17,000	18,900	26,700
Housing	8,800	16,400	19,800	30,000	33,000
Subtotal	74,300	115,300	155,100	202,500	270,000
Design Contingencies	11,100	17,300	23,300	30,400	40,500
Total	$85,400	$132,600	$178,400	$232,900	$310,500

Note: Housing requirements from smallest plant capacity to largest are 100, 210, 275, 500, and 600 sq ft respectively. Height of building is 14 ft.

TABLE 21. CONSTRUCTION COST SUMMARY FOR PACKAGE LIME SOFTENING - TWO STAGE

Cost Category	Plant Capacity, gpd 15,000	150,000	430,000	750,000	1,000,000
Excavation & Site Work	$ 5,800	$ 9,300	$ 11,100	$ 14,000	$ 16,400
Manufactured Equipment	53,500	80,300	107,000	139,100	167,500
Concrete	1,800	4,200	5,500	10,000	11,800
Labor, Installation	23,400	30,400	46,700	60,700	73,000
Pipe & Valves	10,400	20,900	28,200	33,400	91,800
Electrical, Instrumentation	14,900	21,500	29,800	33,000	46,900
Housing	15,600	26,000	31,400	44,000	48,000
Subtotal	125,400	192,600	259,700	334,200	455,400
Design Contingencies	18,800	28,900	39,000	50,100	68,300
Total	$144,200	$221,500	$298,700	$384,300	$523,700

Note: Housing requirements from smallest plant capacity to largest are 200, 420, 550, 1,000, and 1,200 sq ft respectively. Height of building is 14 ft.

Operation and Maintenance Requirements and Costs

Process electrical requirements are for feeding of lime and soda ash, rapid mix, flocculators, sludge pumping, and refrigeration of the liquid carbon dioxide (two larger size plants only). Hydrated lime was used for the three smaller sizes, and quicklime with a slaker was used for the two larger sizes. Hydrated lime is fed directly into the rapid mix basin, and the lime slurry from the slaker is fed into the rapid mix basin by gravity. Building energy for lighting, ventilation, and heating is based on an annual average of 209.8 kwh/m^2/y (19.5 kwh/sq ft/yr). An average daily lighting requirement of 3 hours per day is included in this value.

Maintenance materials are for laboratory supplies, replacement components for chemical feeders, sludge pumps and treatment units, and miscellaneous components.

Operational labor is required for daily chemical and process adjustments, as well as addition of chemicals to the feed hoppers in smaller plants that use bagged chemicals. Maintenance labor is required for equipment repair and maintenance.

Operation and maintenance requirements are summarized in Table 22 for single stage softening and in Table 23 for two stage softening. Figures 13 and 14 illustrate the operation and maintenance requirements for single stage and two stage, respectively.

Typical Chemical Requirements and Costs

Chemicals used at a typical softening plant include lime, soda ash (in certain cases), and carbon dioxide. Dosages of lime and soda ash are a function of the type of hardness present, and desired hardness in the finished water.

It is difficult to describe a typical chemical requirement, due to the widely varying quality of different water supplies. Thus, chemical requirements and costs were developed for two different water supplies. These two cases are:

	Case 1	Case 2
Carbon Dioxide - mg/L	4	8
Calcium - mg/L as Ca	85	147
Magnesium - mg/L as Mg	10	16
Carbonate hardness - mg/L as $CaCO_3$	253.7	240
Noncarbonate hardness - mg/L as $CaCO_3$	0	193.3

In both cases, the water is to be softened to 80 mg/L hardness, and the solubility of $CaCO_3$ is assumed to be 30 mg/L. In Case 2, 35 mg/L of excess lime is used.

TABLE 22. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE LIME SOFTENING SINGLE STAGE

Plant Flow Rate, gpd	Energy, kwh/yr Building	Energy, kwh/yr Process	Energy, kwh/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
15,000	2,000	7,600	9,600	1,900	1,095	14,600
150,000	4,100	10,200	14,300	2,900	1,095	16,000
430,000	5,400	15,600	21,000	3,900	1,460	21,400
750,000	9,800	34,600	44,400	4,900	1,460	24,100
1,000,000	11,700	38,800	50,500	6,100	1,830	29,800

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 23. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE LIME SOFTENING TWO STAGE

Plant Flow Rate, gpd	Energy, kwh/yr Building	Energy, kwh/yr Process	Energy, kwh/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/Yr
15,000	3,900	12,600	16,500	3,200	1,460	20,400
150,000	8,200	17,000	25,200	4,800	1,460	22,600
430,000	10,700	26,000	36,700	6,400	1,830	29,100
750,000	19,500	52,600	72,100	8,100	1,830	33,300
1,000,000	23,400	59,600	83,000	12,300	2,190	42,200

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Required chemical dosages and costs for these two cases would be as follows:

Case 1	Chemical Cost, $/ton	Required Dosage, lb/million gal	Cost $/million gal
Lime - as $Ca(OH)_2$	90	704.1	31.70
Soda Ash	220	0	0
Carbon Dioxide	200	41.7	4.17
			$ 35.87 mil/gal
Case 2			
Lime - as $Ca(OH)_2$	90	1,189	53.51
Soda Ash	220	592.2	65.14
Carbon Dioxide	200	166.8	16.68
			$135.33 mil/gal

Field Data Collection

Lime softening operating data were collected at Western Springs, Illinois, and Olympia Fields, Illinois. The Western Springs plant has a design capacity of 13,096 m^3/d (3.46 mgd) and an operating rate of 4,504 m^3/d (1.19 mgd) and the Olympia Fields plant has a design capacity of 2,725 m^3/d (0.72 mgd) and an operating rate of 1,926 m^3/d (0.509 mgd). Both installations use single stage softening.

A comparison of actual operating results with Figures 13 and 14 is shown in the following:

	Western Springs		Olympia Fields	
	Field Data	Data From Figures 13 and 14	Field Data	Data From Figures 13 and 14
Electrical Energy, kwh/hr				
Process	-	40,000	-	20,000
Building	-	14,000	-	6,000
Total	639,900	54,000	28,200	26,000
Maintenance Material, $/yr	-	7,000	-	4,000
Labor, hr/yr	1,970	2,000	3,120	1,500

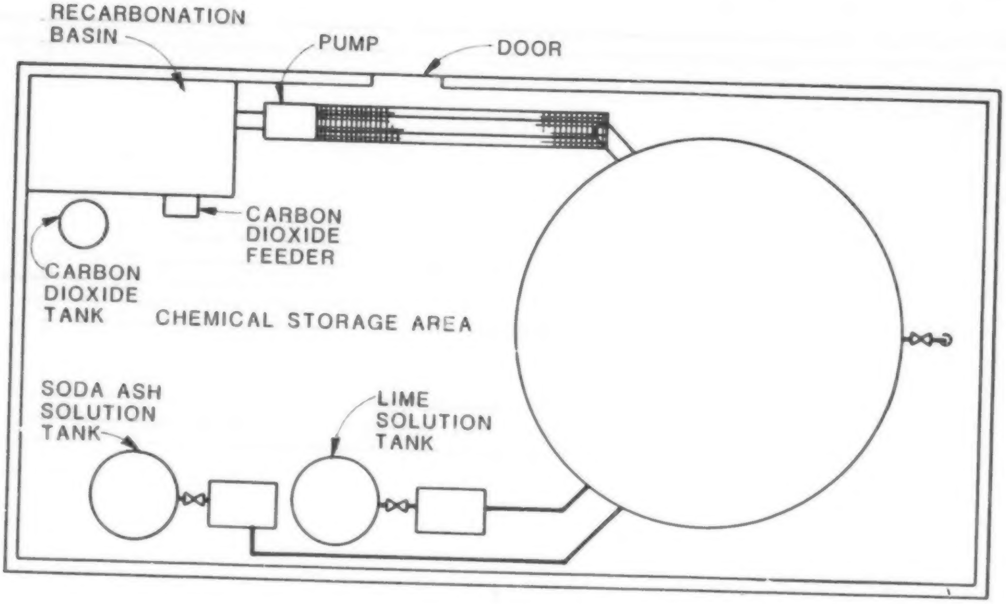
The discrepancy in total electrical energy at Western Springs is believed to be due to the inclusion of product water pumping in the field data. At Olympia Fields, the difference in labor requirements may be attributable to incorrect disaggregation of total plant labor requirements into labor requirements for individual unit processes. Field data collection did not include a category for maintenance material.

References

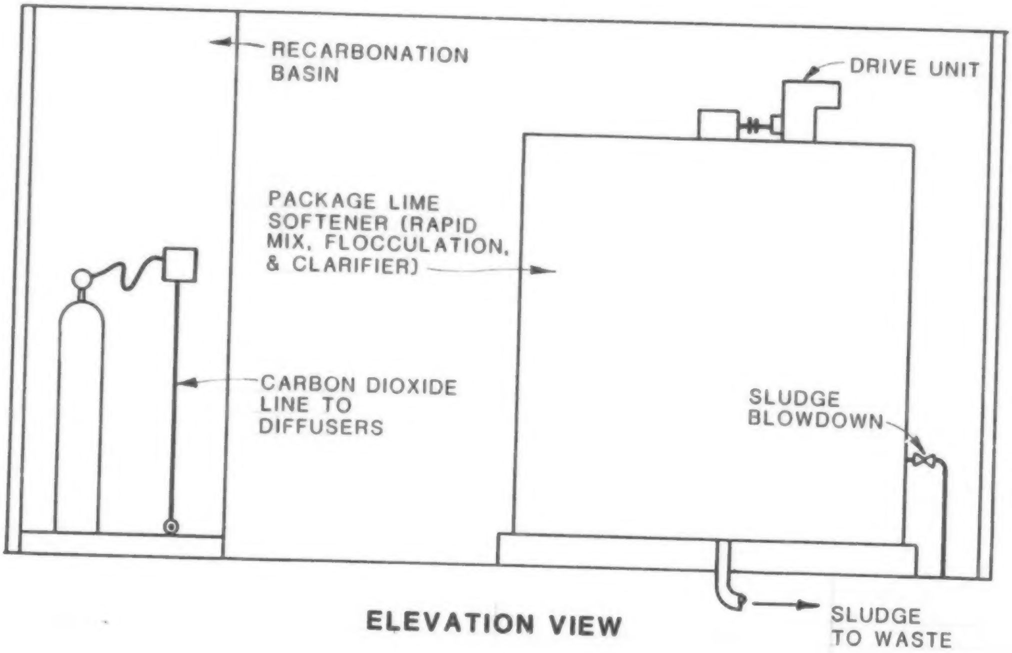
1. Water Treatment Plant Design, American Water Works Association, Inc., Denver, Colorado, 1979, pp. 209-226.

2. Sanks, R.L., Editor, "Water Treatment Plant Design for the Practicing Engineer," Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1978, pp. 567-596.

3. Zipf, K.A., and R.G. Luthy, "Chemical Equilbria in Split-Treatment Softening of Water," Journal AWWA, June, 1981, Vol, 73, pp. 304-311.


RECARBONATION BASIN
PUMP
DOOR
CARBON DIOXIDE FEEDER
CARBON DIOXIDE TANK
CHEMICAL STORAGE AREA
SODA ASH SOLUTION TANK
LIME SOLUTION TANK

PLAN VIEW


RECARBONATION BASIN
DRIVE UNIT
PACKAGE LIME SOFTENER (RAPID MIX, FLOCCULATION, & CLARIFIER)
CARBON DIOXIDE LINE TO DIFFUSERS
SLUDGE BLOWDOWN
SLUDGE TO WASTE

ELEVATION VIEW

Figure 11. Typical package lime softening installation.

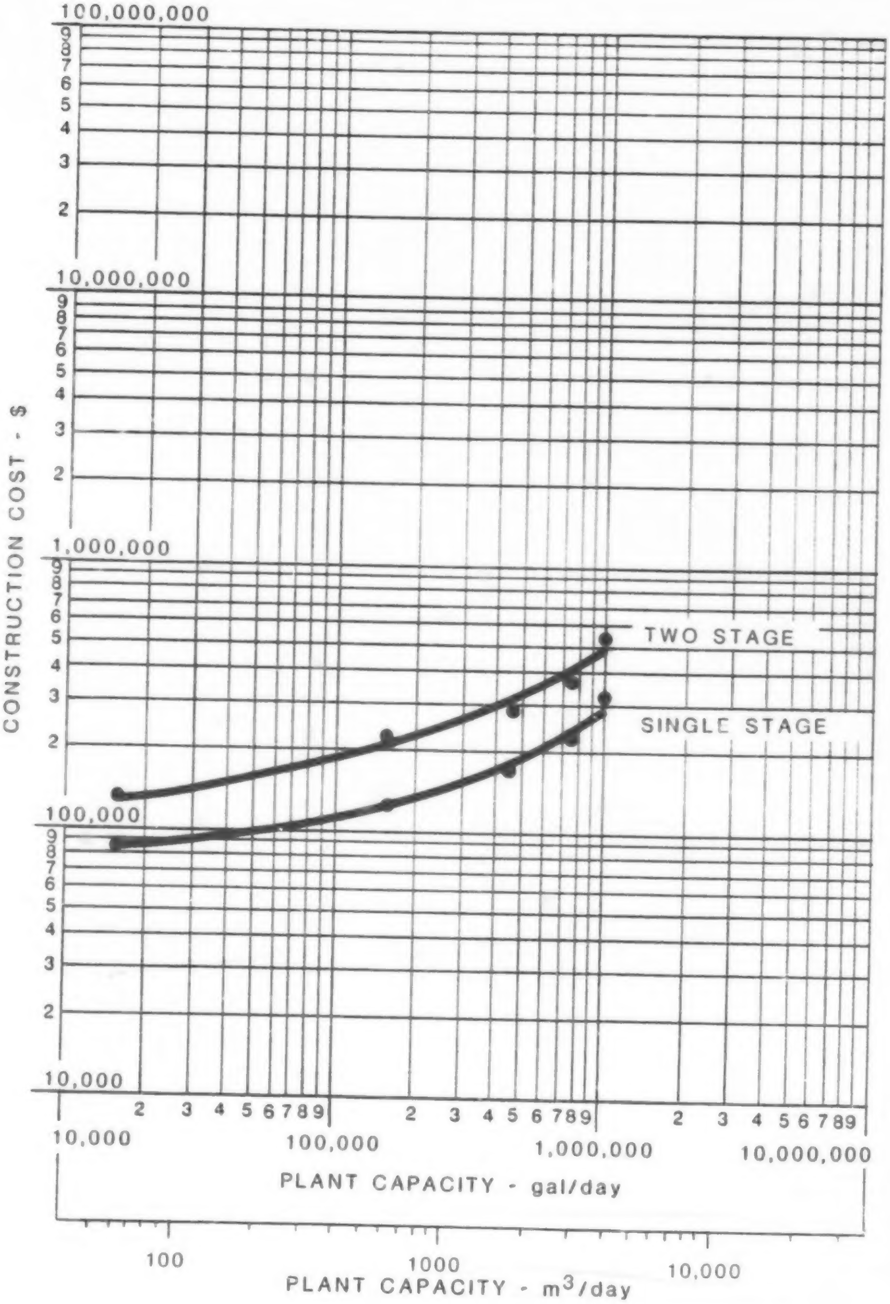


Figure 12. Construction cost for package lime softening plants, single stage and two stage.

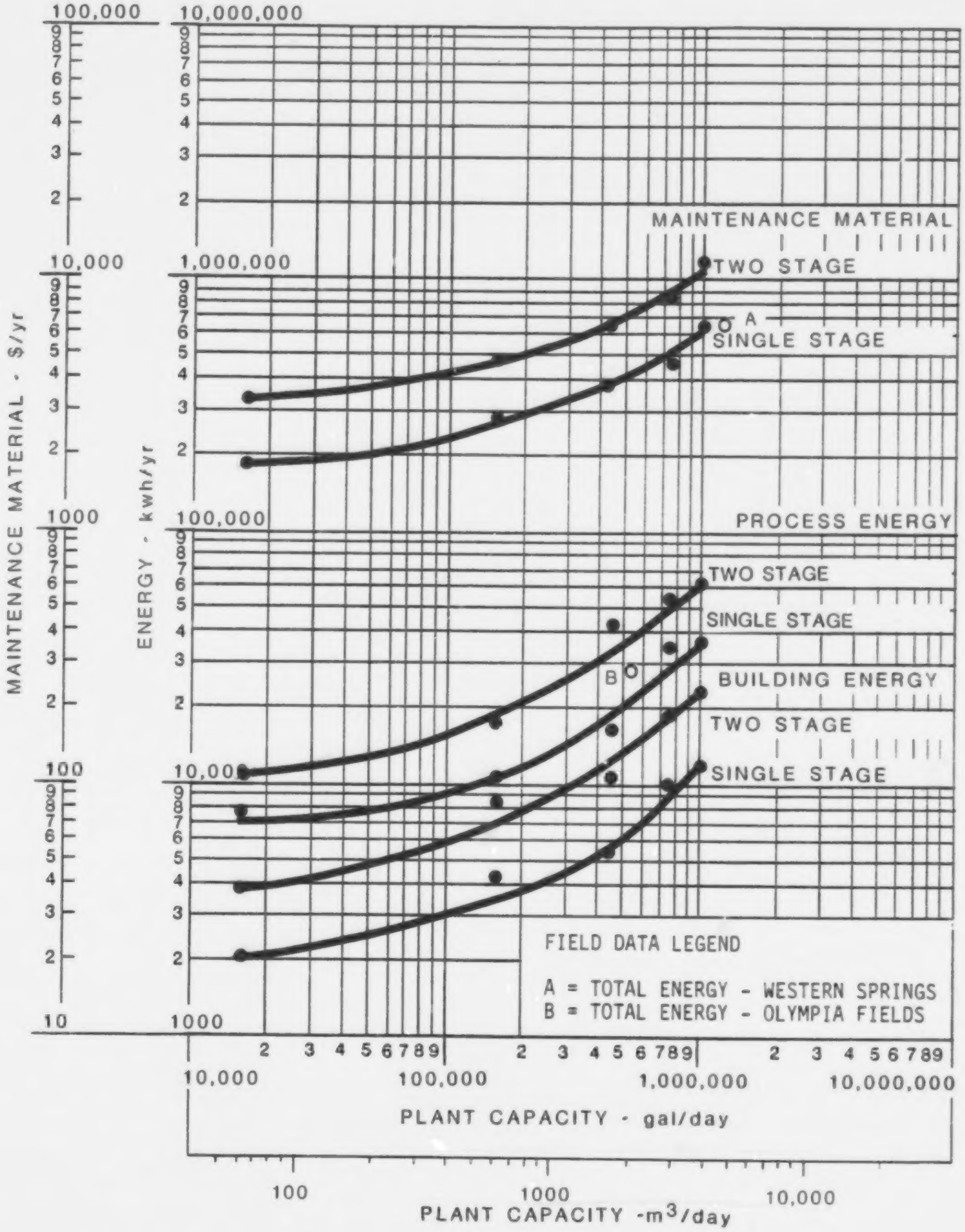


Figure 13. **Operation and maintenance requirements for package lime softening plants, single stage and two stage - building energy, process energy, and maintenance material.**

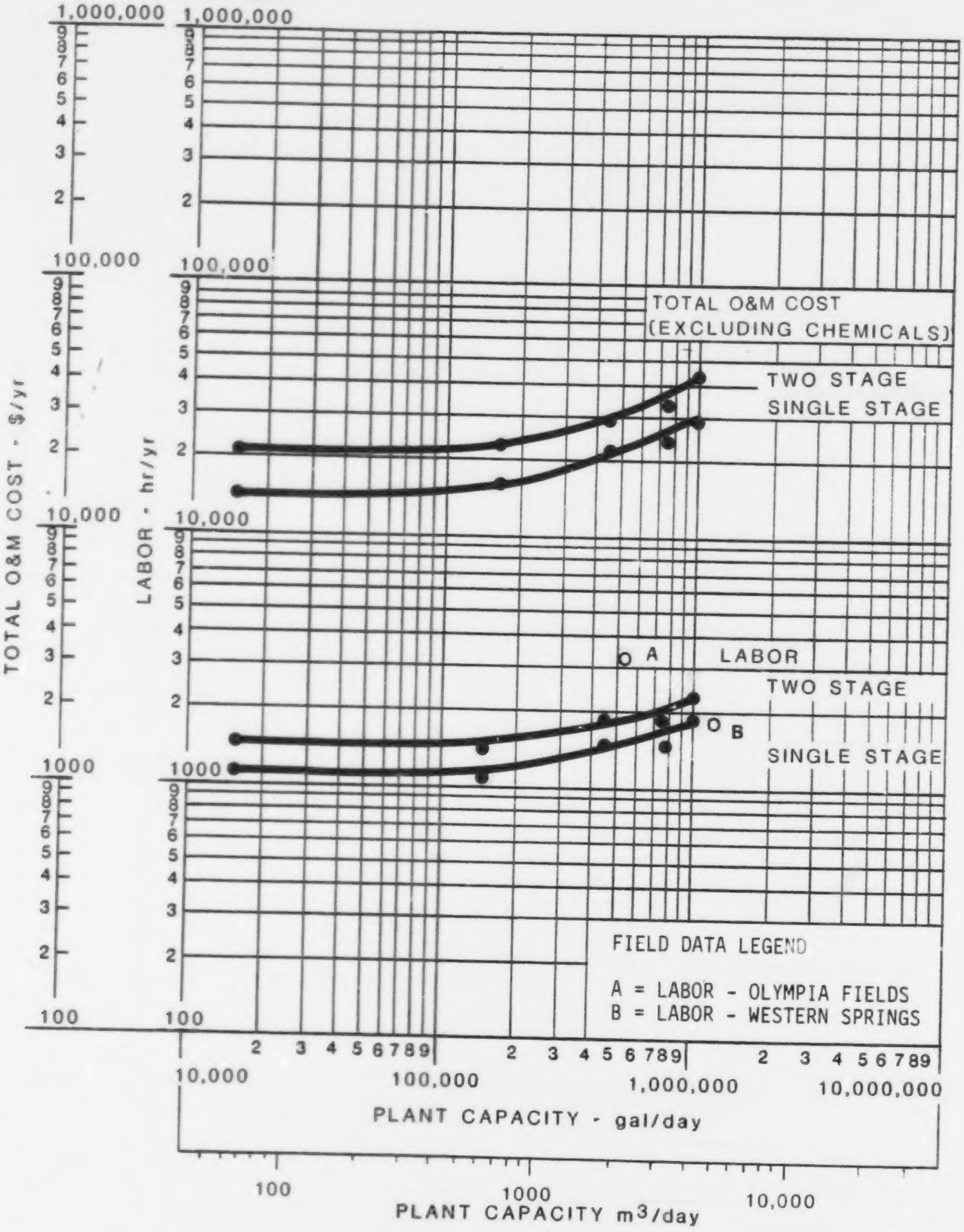


Figure 14. Operation and maintenance requirements for package lime softening plants, single stage and two stage - labor and total O&M cost.

PACKAGE PRESSURE FILTRATION PLANTS

Introduction

Package pressure filters are used extensively for iron and manganese removal from well waters, and in some states, as a final treatment process following chemical coagulation and clarification of surface waters. Pressure filters are available from many manufacturers with either rapid sand, dual-media or mixed-media filter beds. Units can be either totally automatic or manual in operation. Some manufacturers provide factory built, skid-mounted units complete with pumps, automatic control valves, and control panel. Other manufacturers furnish only the filter vessels which must be assembled along with valves, piping, and controls at the job site.

Impact of Raw Water Quality on Treatment Cost

In iron and manganese removal applications, chlorine and potassium permanganate are commonly applied to well water supplies to oxidize these constituents prior to filtration. Chlorine dioxide may also be used as an oxidant prior to filtration. Treatment costs are directly related to the chemical dosages required to remove these materials from the raw water. Also, the concentration of these contaminants and the required chemical dosages affects the filtration rates. For waters with high concentrations of iron and/or manganese, lower filtration rates may be necessary, which will increase the unit cost of the filtered water.

Construction Costs

Costs were developed for skid-mounted units including a single ASME code pressure vessel with internal piping, automatic control valves, filter media (mixed media), backwash pump, surface wash pump, face piping and piping within the battery limits shown, instrumentation, and control panel. Included in the costs are chemical feeders for chlorine, potassium permanganate, and polymer. A typical installation is shown in Figure 15. Conceptual design criteria for the filter vessels and housing are shown in Table 24, along with treatment capacities at filtration rates of 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft). The filters are designed for automatic, unattended operation with backwash initiated by excessive headloss or elapsed operating time.

Construction costs are tabulated in Table 25 and are also presented in Figure 16. Excluded from these costs are raw water pumps, finished water pumps, and clearwell storage.

Operation and Maintenance Requirements and Costs

Process energy is required for backwash and surface wash pumping, chemical mixing and chemical feed pumping. Process energy was calculated for backwash frequencies of both once and twice per day, at flow rates of both 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft). Process energy for filter supply and product water pumping are not included.

TABLE 24. CONCEPTUAL DESIGNS FOR PACKAGE PRESSURE FILTRATION PLANTS

Filter Vessels			Housing		Plant Capacity, gpm	
Number of Units	Filter Area, sq ft	Diameter, ft	LxWxH, ft	Area, sq ft	Filtration Rate 2 gpm/sq ft	Filtration Rate 5 gpm/sq ft
1	0.34	0.67	10 x 10 x 10	100	0.7	1.7
1	3.14	2	16 x 10 x 10	160	6.3	16
1	12.6	4	20 x 12 x 10	240	25	63
1	28.3	6	24 x 14 x 14	336	57	142
1	50	8	28 x 18 x 14	504	100	250
1	79	10	30 x 22 x 14	660	158	395

TABLE 25. CONSTRUCTION COST SUMMARY FOR PACKAGE PRESSURE FILTRATION PLANTS

	Filter Area, sq ft					
Cost Category	0.34	3.14	12.6	28.3	50	79
Excavation and Sitework	$ 1,400	$ 1,900	$ 2,800	$ 3,900	$ 5,800	$ 6,900
Manufactured Equipment	9,800	25,900	51,600	59,000	67,600	83,700
Concrete	1,800	2,700	3,900	5,400	8,000	10,600
Labor, Installation	1,400	4,900	10,500	12,100	14,000	17,500
Pipe and Valves	600	2,200	4,700	5,400	6,300	7,800
Electrical, Instrumentation	2,500	6,300	12,000	14,600	18,100	22,700
Housing	8,000	11,500	15,600	22,800	29,700	34,300
Subtotal	25,500	55,400	101,100	123,200	149,500	183,500
Design Contingencies	3,800	8,300	15,200	18,500	22,400	27,500
Total	$29,300	$63,700	$116,300	$141,700	$171,900	$211,000

Building energy requirements are for heating, ventilation, and lighting for three hours per day, and are based on an energy usage of 156 kwh/m^2/y (14.5 kwh/sq ft/yr) for buildings that are 3.05 m (10 ft) high, and 209.8 kwh/m^2/y (19.5 kwh/sq ft/yr) for buildings that are 4.27 m (14 ft) high.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, replacement of parts for pumps, instrumentation repair, and general facility maintenance supplies. The maintenance material costs do not include the cost of treatment chemicals, which are discussed in the following section.

Labor requirements were developed assuming that the treatment plant operates automatically and virtually unattended. Operator attention is only necessary to prepare the treatment chemicals, establish proper chemical dosages, carry out routine quality assurance tasks, and perform necessary maintenance tasks. No allowance was included for administrative or laboratory labor requirements.

Operation and maintenance requirements for filtration rates of 4.88 and 12.2 m^3/m^2/h (2 and 5 gpm/sq ft) and backwash frequencies of once and twice per day are summarized in Table 26 and illustrated in Figures 17 and 18.

Typical Chemical Requirements and Costs

Pressure filters for treatment of domestic water supplies are generally limited by regulatory agencies to removal of iron and manganese from groundwaters. For iron removal, chlorine is added to oxidize the iron, converting it to a filterable form. Typically about 1 mg/L of chlorine is required per mg/L of unoxidized iron.

Manganese is more difficult to remove than iron and requires the application of potassium permanganate which is a stronger oxidant than chlorine. Generally about 2 mg/L of permanganate is required to oxidize 1 mg/L of manganese to a filterable form. Often, chlorine plus permanganate are applied to reduce the amount of the more expensive potassium permanganate needed to remove the manganese.

Depending upon the characteristics of the raw water, pH adjustment may be necessary for effective removal of iron and manganese from groundwaters. This adjustment will increase treatment cost. Pressure filters containing manganese "green sand," a naturally occurring zeolite material to which potassium permanganate is fed continuously, are used extensively for iron and manganese removal.

In addition to the oxidant, a polymer filter aid will generally be required to prevent penetration of the finely divided oxidized iron and manganese through the filter bed.

Table 27 provides typical costs for iron and manganese removal using chlorine and potassium permanganate with polymer as a filtration aid. The following unit costs and dosages were used to generate typical treatment costs:

TABLE 26. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE PRESSURE FILTRATION PLANTS

Filter Area, sq ft	Flow Rate, gpm	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Filtration Rate = 2 gpm/sq ft and one backwash/day							
0.34	0.68	1,500	300	1,800	100	160	2,000
3.14	6.28	2,300	300	2,600	300	200	2,700
12.6	25.2	3,500	400	3,900	600	250	3,600
28.3	56.6	6,600	500	7,100	800	290	4,500
50	100	9,800	600	10,400	1,100	320	5,400
79	158	12,900	900	13,800	1,200	360	6,100
Filtration Rate = 2 gpm/sq ft and two backwashes/day							
0.34	0.68	1,500	300	1,800	100	190	2,300
3.14	6.28	2,300	300	2,600	300	240	3,100
12.6	25.2	3,500	500	4,000	800	300	4,400
28.3	56.6	6,600	700	7,300	900	350	5,300
50	100	9,800	1,000	10,800	1,300	380	6,200
79	158	12,900	1,500	14,400	1,500	430	7,300
Filtration Rate = 5 gpm/sq ft and one backwash/day							
0.34	1.7	1,500	300	1,800	100	340	4,000
3.14	15.7	2,300	300	2,600	300	380	4,700
12.6	63	3,500	400	3,900	600	430	5,600
28.3	142	6,600	500	7,100	800	470	6,500
50	250	9,800	600	10,400	1,100	500	7,300
79	395	12,900	900	13,800	1,200	540	8,100
Filtration Rate = 5 gpm/sq ft and two backwashes/day							
0.34	1.7	1,500	300	1,800	100	370	4,300
3.14	15.7	2,300	300	2,600	300	420	5,100
12.6	63	3,500	500	4,000	800	480	6,400
28.3	142	6,600	700	7,300	900	530	7,300
50	250	9,800	1,000	10,800	1,300	560	8,200
79	395	12,900	1,500	14,400	1,500	610	9,200

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor. Twenty-four hour/day operation is assumed.

Chemical	Dosage*	Cost
Chlorine	1 mg/L	$0.37/lb
Potassium Permanganate	2 mg/L	2.20/lb
Polymer	0.2 mg/L	3.00/lb

*Dosage assumes water contains both iron and manganese in concentrations of about 1 mg/L for both constituents.

TABLE 27. TYPICAL CHEMICAL COSTS FOR IRON AND MANGANESE REMOVAL WITH PACKAGE PRESSURE FILTRATION

Average Plant Flow, gpm	Chlorine, $/yr	Potassium Permanganate, $/yr	Polymer, $/yr	Total Chemical Cost, $/yr
1.7	3	31	4	40
16	25	296	40	360
63	98	1,164	158	1,400
142	220	2,625	356	3,200
250	388	4,620	627	5,600
395	613	7,301	990	8,900

Field Data Collection

Field operating data for a pressure filtration plant was collected at Davis Dam, Bullhead City, Arizona. This plant has a filtration surface area of 11.7 m^2 (126 sq ft), a plant design capacity of 3,785 m^3/d (1 mgd), and an average operating rate of 791 m^3/d (0.209 mgd). The plant configuration includes raw water pumping, pressure filtration, and gas chlorination. The process energy information collected includes all three of these unit processes, while the labor requirement includes the pressure filter and chlorination.

A comparison of field operating data and Figures 17 and 18 for pressure filtration and Figures 81 and 82 for gas chlorination is shown following:

		Data from Figures 17, 18, 81 and 82		
	Field Data	Pressure Filters	Chlorination	Total
Electrical Energy, kwh/hr				
Process	-	1,000	1,100	2,100
Building	-	16,000	1,200	17,200
Total	119,260*	17,000	2,300	19,300
Maintenance Material, $/yr	-	1,600	300	1,900
Labor, hr/yr	138	450	180	630

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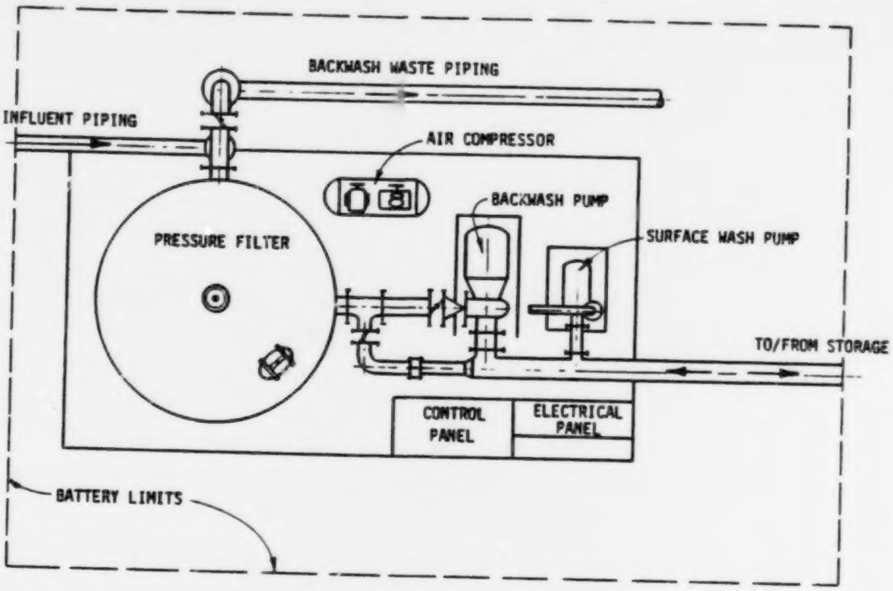
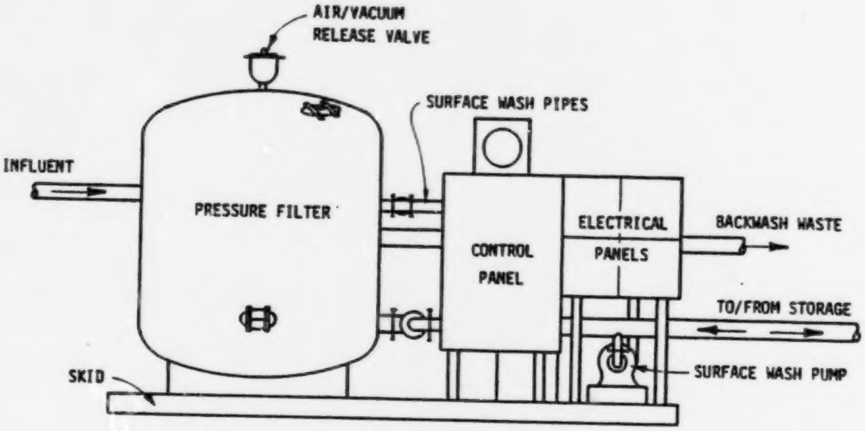
*Includes raw water pumping. Pumping head is not known.

As shown, field data were not disaggregated into separate categories for pressure filters and gas chlorination. Total electrical energy requirements experienced in the field are higher than the figures because the field data includes raw water pumping. There is no explanation for the low labor requirement, except that the plant is only operated at 21% of design capacity.


BACKWASH WASTE PIPING
INFLUENT PIPING
AIR COMPRESSOR
BACKWASH PUMP
PRESSURE FILTER
SURFACE WASH PUMP
TO/FROM STORAGE
CONTROL PANEL
ELECTRICAL PANEL
BATTERY LIMITS

PLAN


AIR/VACUUM RELEASE VALVE
SURFACE WASH PIPES
INFLUENT
PRESSURE FILTER
ELECTRICAL PANELS
BACKWASH WASTE
CONTROL PANEL
TO/FROM STORAGE
SKID
SURFACE WASH PUMP

ELEVATION

Figure 15. Typical package pressure filter installation

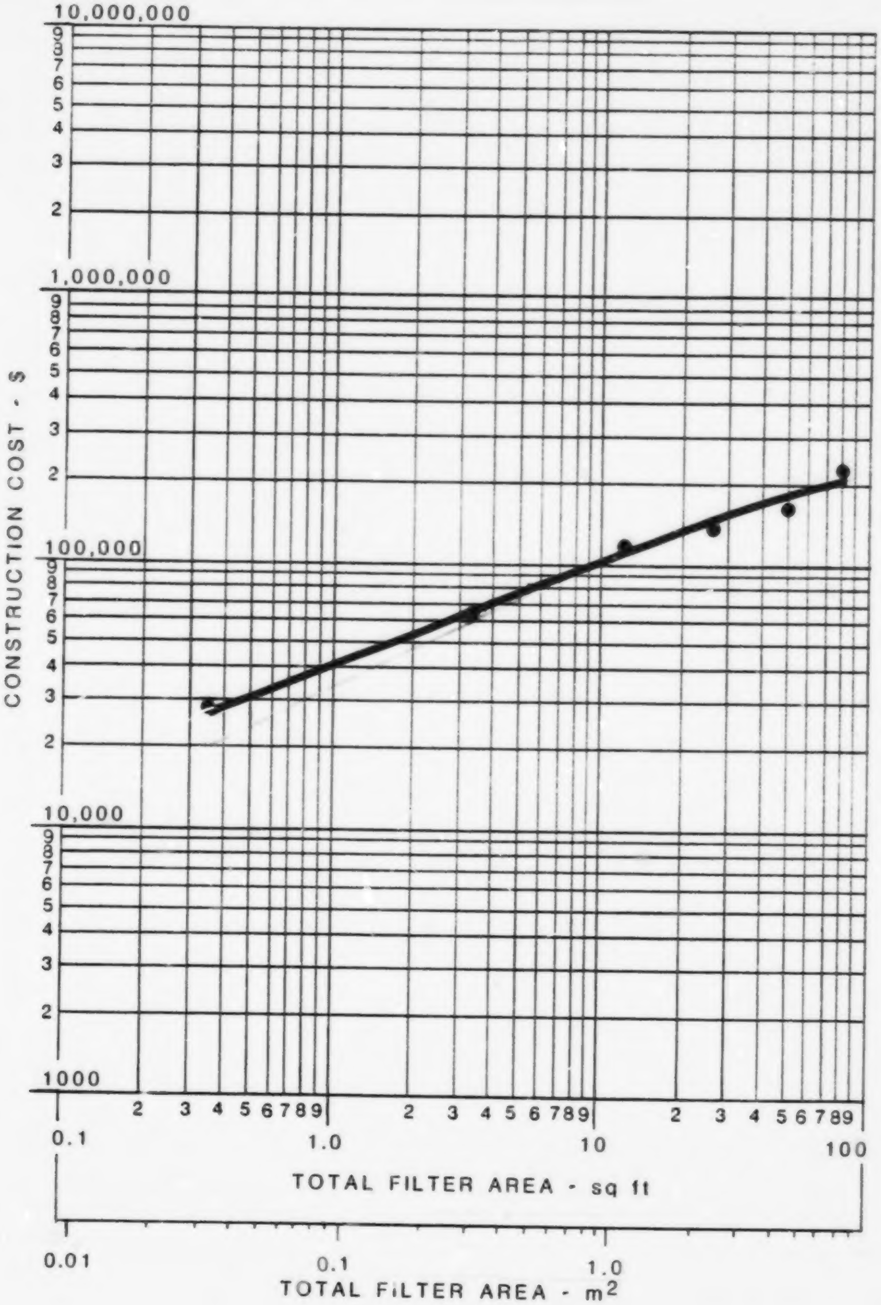


Figure 16. **Construction cost for package pressure filtration plants.**

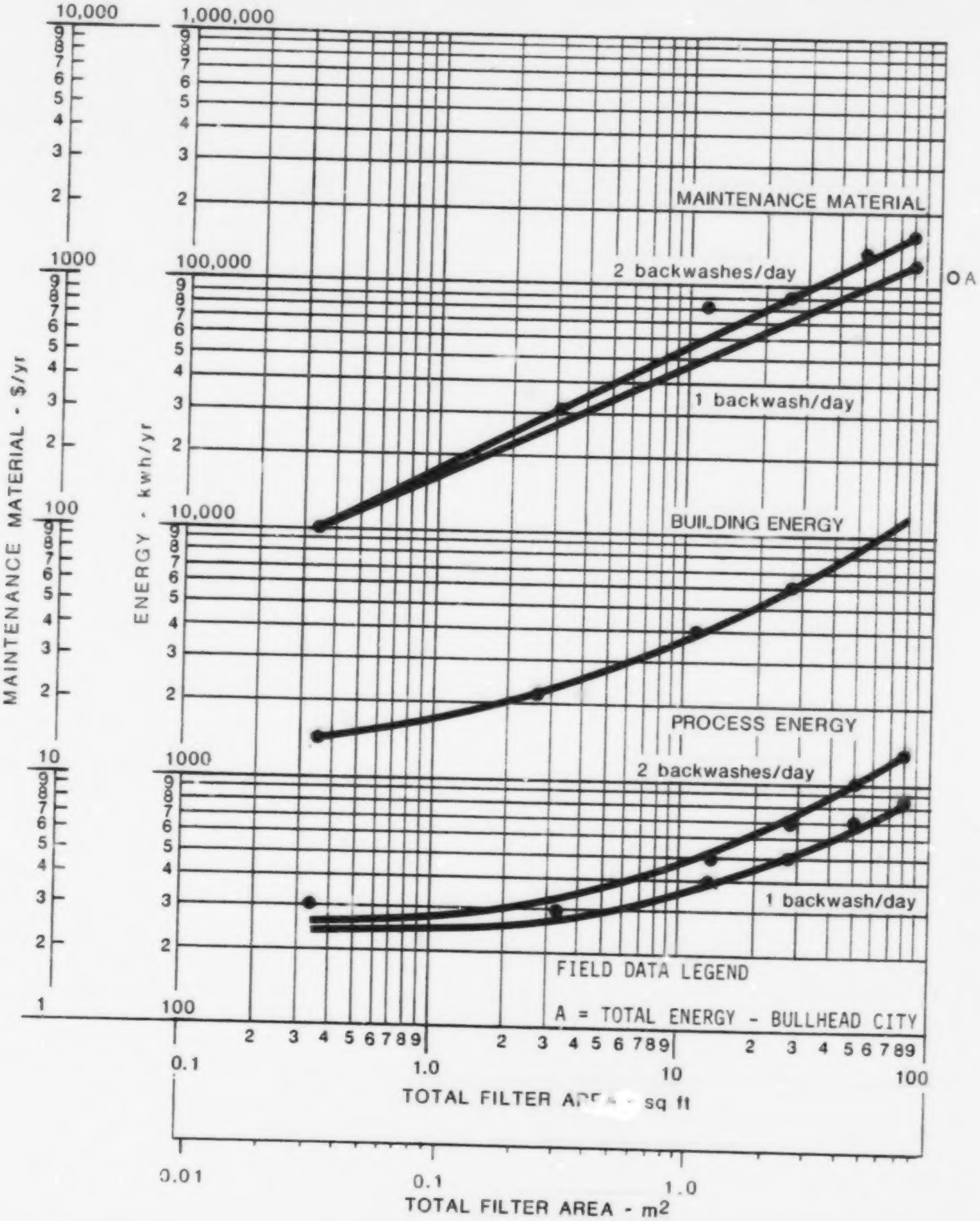


Figure 17. **Operation and maintenance requirements for package pressure filtration plants - building energy, process energy, and maintenance material.**

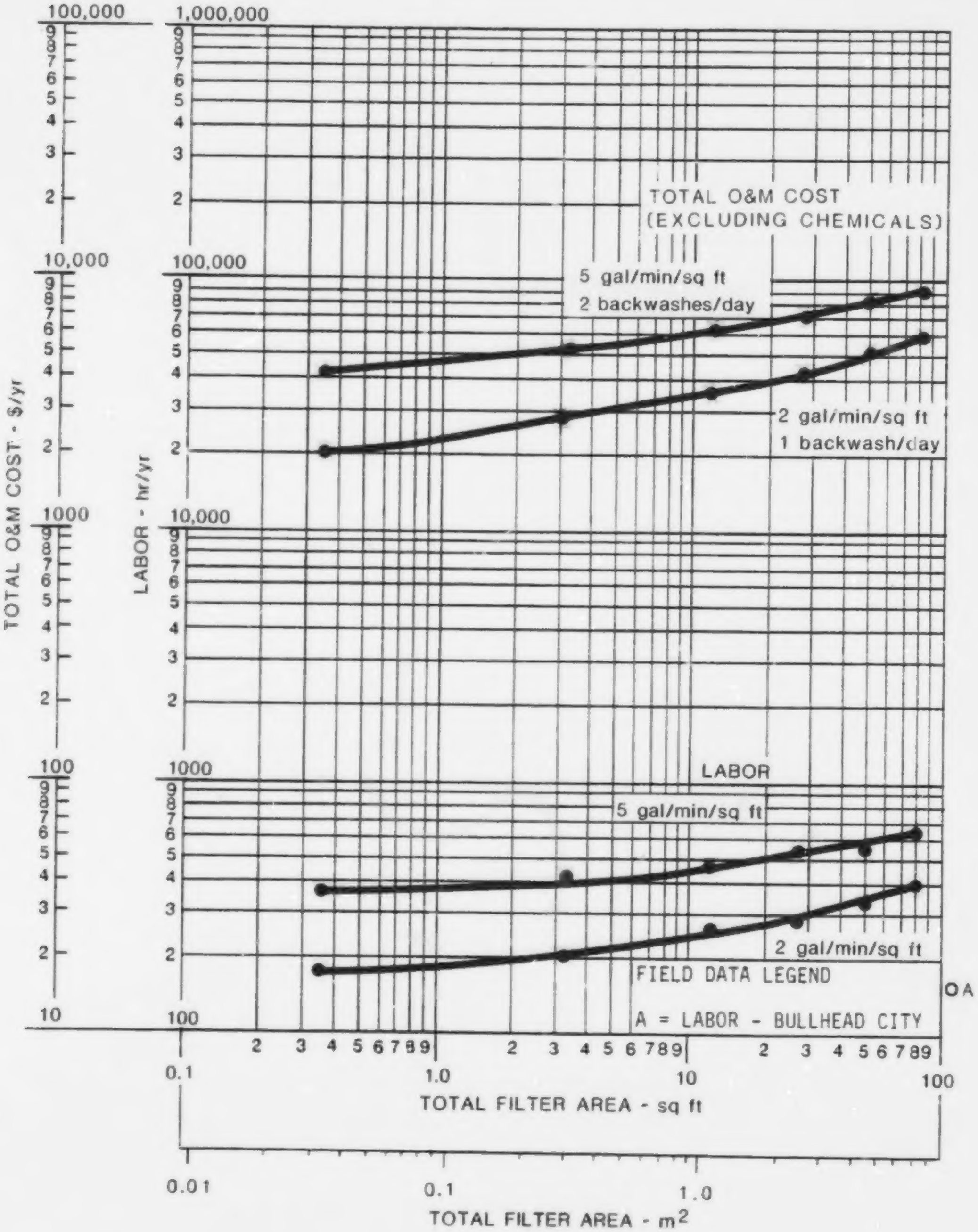


Figure 18. Operation and maintenance requirements for package pressure filtration plants - labor and total O&M cost.

PACKAGE GRAVITY FILTRATION PLANTS

Introduction

Package gravity filters, when used for treating surface water supplies, are typically preceeded by pretreatment processes such as flash mix basins, flocculator clarifiers or contact basins, depending upon the quality of raw water. Gravity filters may also be used for iron and manganese removal from ground water, following aeration or chemical oxidation, or following solids contact clarifiers in lime softening operations.

Package gravity filters are furnished in cylindrical or rectangular, factory fabricated steel tankage and are generally supplied with all internal components including wash trough, surface wash and pipe lateral underdrain. Automatic control valves, automatic backwash programmer, and filter media are generally furnished by the manufacturer for installation at the site. Backwash pumps, surface wash pumps, filter supply pumps, and filter face piping are generally furnished by the installing contractor.

Impact of Raw Water Quality on Treatment Cost

Raw water quality indirectly impacts filtration cost, since it establishes the required dosages of coagulant and coagulant aid applied to pretreatment processes. Generally, as raw water turbidity, color or bacterial concentration increase, higher coagulant dosages are required at resultant higher treatment costs. Filtration rates in excess of 7.32-9.76 $m^3/m^2/h$ (3-4 gpm/sq ft) with dual or mixed media generally require addition of filtration aids, especially when water temperatures drop below 7.2-10°C (45-50°F). In applications where the only pretreatment is flash mixing or contact basins (direct filtration), increased suspended solids loadings to the filters will shorten filtration cycles, thereby requiring more frequent backwashings and reducing the net production of filtered water. For extremely poor quality water, it may be desirable to operate at lower filtration rates, which would proportionately increase the unit cost of treatment.

Construction Costs

Conceptual design information for package gravity filter installations is shown in Table 28. Construction costs were developed using these criteria, for package gravity filter installations employing two, cylindrical open-top tanks with automatic valves and controls. The construction costs include backwash and surface wash pumps and controls, filter face piping, mixed media filter media, polymer storage and feed equipment, and other accessories within the battery limits as shown on the typical layout in Figure 19.

Filter vessels are eight feet tall and discharge through level controlled effluent valves to a below-grade clearwell. Backwashing of the filters is automatic according to filter headloss. The facilities are totally enclosed.

The construction costs exclude pretreatment facilities, clearwell storage, and finished water pumping. Construction costs are shown in Table 29, as well as in Figure 20.

TABLE 28. CONCEPTUAL DESIGNS FOR PACKAGE GRAVITY FILTRATION PLANTS

	Filter Vessels		Housing		Plant Capacity, gpm	
Number of Units	Filter Area, sq ft	Diameter, ft	LxWxH, ft	Area, sq ft	Filtration Rate 2 gpm/sq ft	Filtration Rate 5 gpm/sq ft
2	3.14	2	14 x 13 x 14	182	12.6	32
2	12.6	4	20 x 18 x 14	360	50	125
2	28.3	6	24 x 20 x 14	480	114	285
2	50	8	30 x 24 x 14	720	200	500
2	79	10	40 x 28 x 14	1,120	316	790
2	113	12	46 x 30 x 14	1,380	452	1,130

TABLE 29. CONSTRUCTION COST SUMMARY FOR PACKAGE GRAVITY FILTRATION PLANTS

	Filter Area, sq ft					
Cost Category	6.3	25	57	100	158	226
Excavation and Sitework	2,100	4,200	5,600	7,600	10,500	12,900
Manufactured Equipment	8,600	14,200	21,400	36,100	54,200	68,700
Concrete	3,100	5,800	7,700	10,700	16,800	19,300
Labor, Installation	2,700	3,700	5,600	9,800	15,200	19,300
Pipe and Valves	4,700	8,600	11,700	15,600	24,000	32,300
Electrical, Instrumentation	4,300	8,000	10,200	15,300	22,400	28,200
Housing	14,900	24,500	28,800	36,700	45,900	51,100
Subtotal	40,400	69,000	91,000	131,800	189,000	231,800
Design Contingencies	6,100	10,400	13,700	19,800	28,400	34,800
Total	46,500	79,400	104,700	151,600	217,400	266,600

Operation and Maintenance Requirements and Costs

Process energy is required for polymer preparation and feed equipment, backwash pumping and surface wash pumping. Process energy was calculated for backwash frequencies of both once and twice per day, at filtration rates of 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft). Process energy for filter supply pumping and product water pumping are not included.

Building energy usage is based upon 209.8 $kwh/m^2/y$ (19.5 kwh/sq ft/yr) for heating, ventilating and lighting. This usage assumes use of building lights for three hours/day.

Maintenance materials are for replacement of components which wear out or breakdown during normal operations. Typical maintenance material items are pump seals, lubricants, replacement parts for pumps, instrumentation repair, and general facility maintenance supplies. The maintenance material costs do not include the cost of treatment chemicals, which are discussed in the following section. Labor requirements cover both maintenance and operation, with the majority of the labor required for routine operations. The operator is required on a daily basis to check the mechanical operation of the filters, to insure that proper chemical dosages are being maintained to produce the desired filtered water quality and to perform routine testing and general maintenance and housekeeping of the facilities. Administrative labor is not included.

Operation and maintenance requirements and costs are summarized in Table 30 for plant capacities at filtration rates of 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft) and backwash frequencies of once and twice per day. These requirements and costs are also shown in Figures 21 and 22.

Typical Chemical Requirements and Costs

The use of polymers as filtration aids varies widely between plants depending upon the type of filtration media, filtration rates, pretreatment processes, water temperature, raw water quality, and other factors. In general, dosages will range from less than 0.01 mg/L to as much as 0.2 mg/L. A typical dosage would be 0.05 mg/L. Chemical costs associated with use of polymer as a filtration aid at a 0.05 mg/L dosage are presented in Table 31 for filtration rates of 4.88 and 12.2 $m^3/m^2/h$ (2 and 5 gpm/sq ft). A unit cost for polymer of \$6.60/kg (\$3.00 per lb) was assumed.

Field Data Collection

Field operating data for a gravity sand filter plant was collected at Safford, Arizona. This plant had a filtration surface area of 29.0 m^2 (312.5 sq ft), a plant design capacity of 2,650 m^3/d (0.7 mgd), and an average operating rate of 590 m^3/d (0.156 mgd). The plant is only used during portions of the year, when runoff is low and there is little silt and suspended material in the source water. Field data included requirements for the sand filter and a gas chlorinator, and there was no division of the requirements between these two processes.

TABLE 30. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE GRAVITY FILTRATION PLANTS

Filter Area, sq ft	Flow Rate, gpm	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Filtration Rate = 2 gpm/sq ft and one backwash/day							
6.3	12.6	3,600	200	3,800	500	250	3,500
25	50	7,000	300	7,300	1,000	320	5,000
57	14	9,400	500	9,900	1,400	380	6,300
100	200	14,100	900	15,000	1,500	420	7,200
158	316	21,900	1,300	23,200	1,600	470	8,400
226	452	26,900	1,900	28,800	1,700	510	9,300
Filtration Rate = 2 gpm/sq ft and two backwashes/day							
6.3	12.6	3,600	200	3,800	600	300	4,200
25	50	7,000	500	7,500	1,300	380	6,000
57	114	9,400	1,000	10,400	1,800	460	7,600
100	200	14,100	1,700	15,800	1,900	500	8,500
158	316	21,900	2,600	24,500	2,000	560	9,900
226	452	26,900	3,600	30,500	2,100	610	11,000
Filtration Rate = 5 gpm/sq ft and one backwash/day							
6.3	32	3,600	200	3,800	500	430	5,500
25	125	7,000	300	7,300	1,000	500	7,000
57	285	9,400	500	9,900	1,400	560	8,300
100	500	14,100	900	15,000	1,500	600	9,200
158	790	21,900	1,300	23,200	1,600	650	10,400
226	1130	26,900	1,900	28,800	1,700	690	11,300
Filtration Rate = 5 gpm/sq ft and two backwashes/day							
6.3	32	3,600	200	3,800	600	480	6,200
25	125	7,000	500	7,500	1,300	560	8,000
57	285	9,400	1,000	10,400	1,800	640	9,600
100	500	14,100	1,700	15,800	1,900	680	10,500
158	790	21,900	2,600	24,500	2,000	740	11,900
226	1130	26,900	3,600	30,500	2,100	790	12,900

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor. Twenty-four hour/day operation is assumed.

TABLE 31. TYPICAL CHEMICAL COSTS FOR PACKAGE GRAVITY FILTRATION PLANTS

Total Filter Area, sq ft	Polymer, lbs/yr		Cost, $/yr	
	2 gpm/sq ft	5 gpm/sq ft	2 gpm/sq ft	5/gpm/sq ft
6.3	3	7	10	25
25	11	27	33	85
57	24	59	75	180
100	43	105	130	315
158	68	166	205	500
226	97	238	295	715

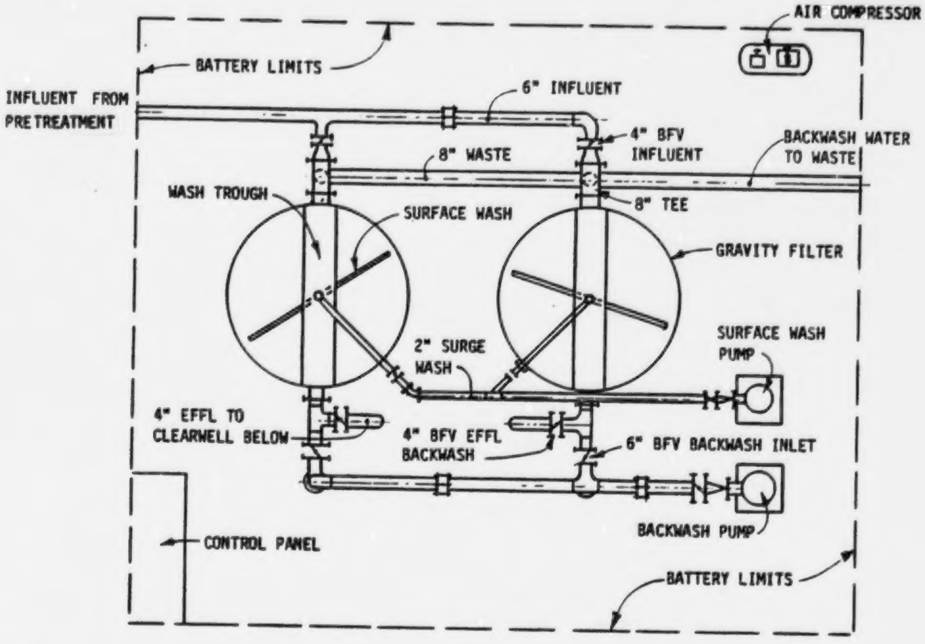
Notes: 1. Polymer dosage is 0.05 mg/L.
2. Polymer cost is $3.00/lb.

A comparison of field operating data and the cost data in Figures 21, 22, 81, and 82, assuming one filter backwash/day and using the filtration rate curve for 4.88 $m^3/m^2/h$ (2 gpm/sq ft) is shown following:

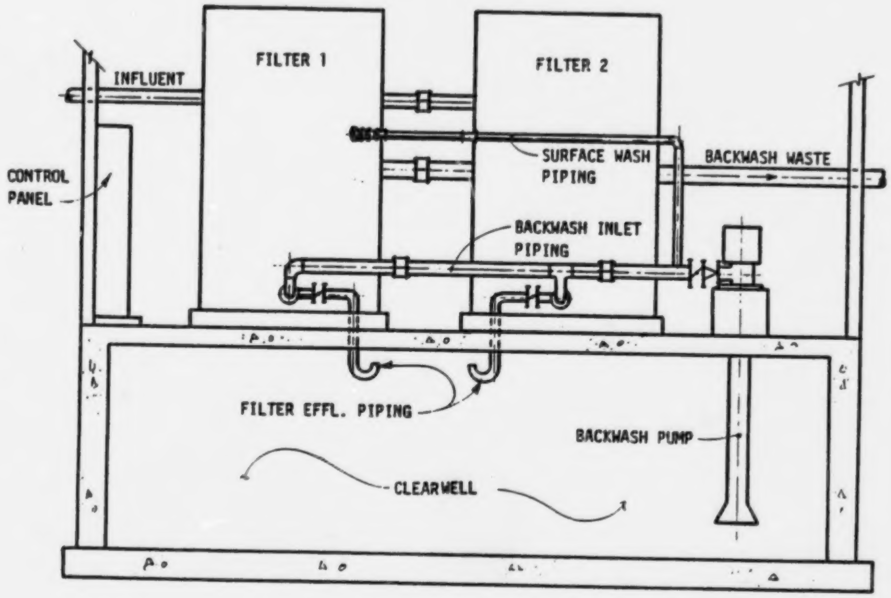
		Data from Figures 21, 22, 81 and 82		
	Field Data	Sand Filters	Chlorination	Total
Electrical Energy, kwh/hr				
Process	-	4,800	1,400	6,200
Building	-	27,000	1,200	28,200
Total	18,000	31,800	2,600	34,400
Maintenance Material, $/yr	-	1,600	350	1,950
Labor, hr/yr	1,040	670	180	850

Note: Field data is based on one backwash every three days.

Field data electrical energy is lower than the information in Figure 21 because the filter is not enclosed in a building at Safford, while Figure 21 is based upon enclosing the filter in a building. Field data for maintenance material was based upon estimates by utility personnel, and not on actual records. This may be an explanation why the field data are less than the cost from Figures 21 and 81. Field data labor requirements are based upon a projection of actual requirements (for several months per year of operation) to a full-year basis. This potentially could give a high value for field labor, as some labor associated with plant startup and shut down would not be experienced if the plant was operated continuously throughout the year.


AIR COMPRESSOR
BATTERY LIMITS
INFLUENT FROM PRETREATMENT
6" INFLUENT
4" BFV INFLUENT
BACKWASH WATER TO WASTE
8" WASTE
WASH TROUGH
8" TEE
SURFACE WASH
GRAVITY FILTER
SURFACE WASH PUMP
2" SURGE WASH
4" EFFL TO CLEARWELL BELOW
4" BFV EFFL BACKWASH
6" BFV BACKWASH INLET
CONTROL PANEL
BACKWASH PUMP
BATTERY LIMITS

PLAN


FILTER 1
FILTER 2
INFLUENT
CONTROL PANEL
SURFACE WASH PIPING
BACKWASH WASTE
BACKWASH INLET PIPING
FILTER EFFL. PIPING
BACKWASH PUMP
CLEARWELL

ELEVATION

Figure 19. Typical package gravity filter installation.

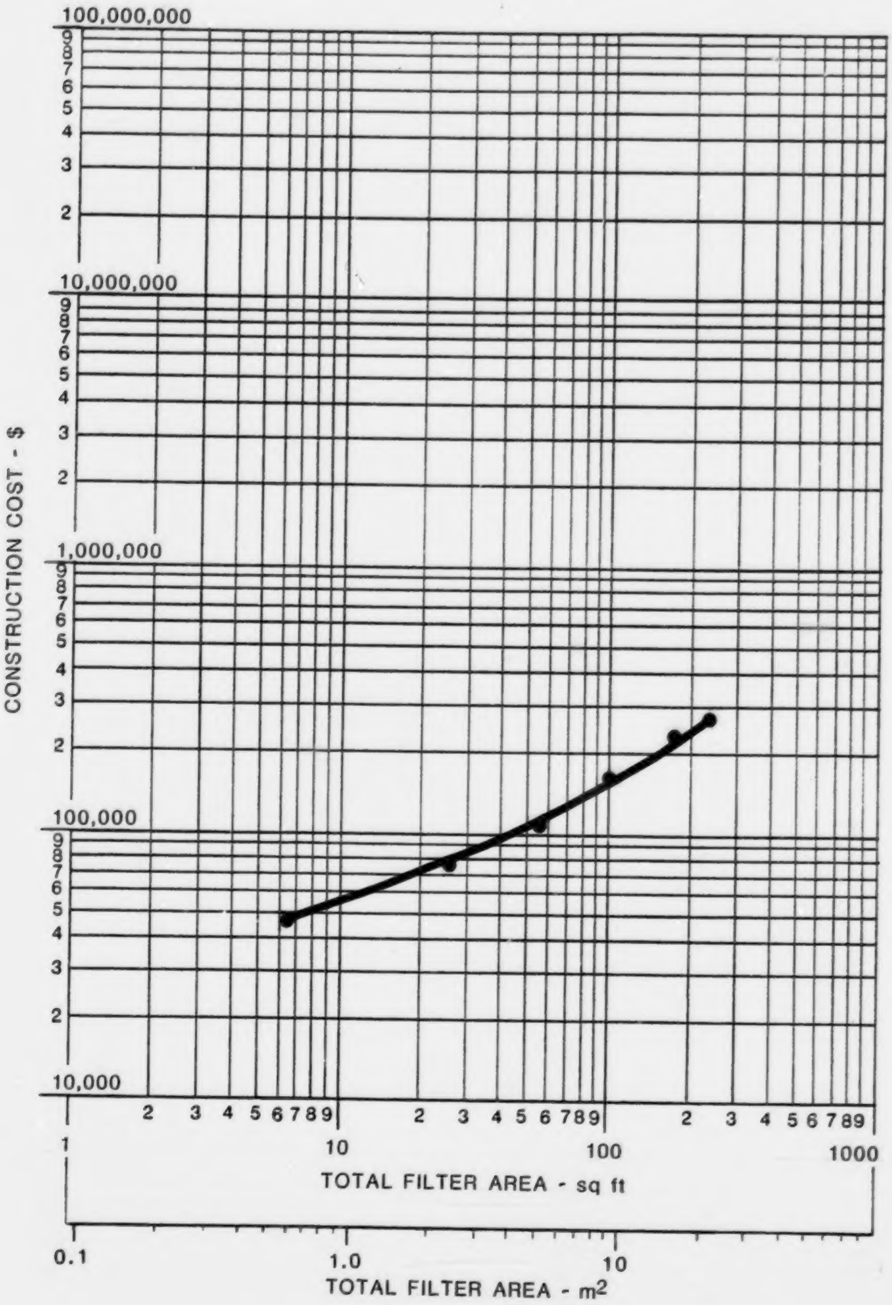


Figure 20. **Construction cost for package gravity filtration plants.**

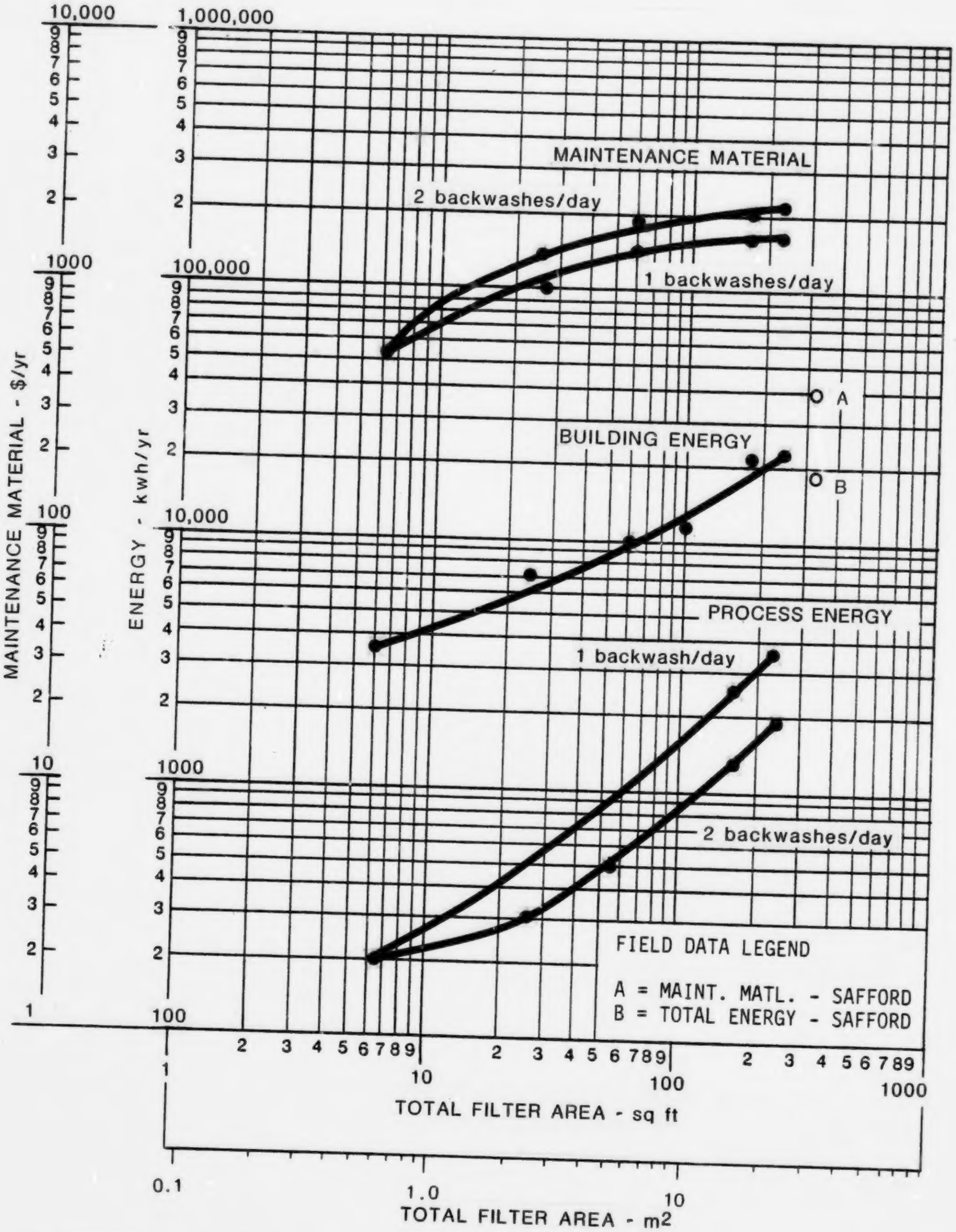


Figure 21. **Operation and maintenance requirements for package gravity filtration plants - building energy, process energy, and maintenance material.**

5A

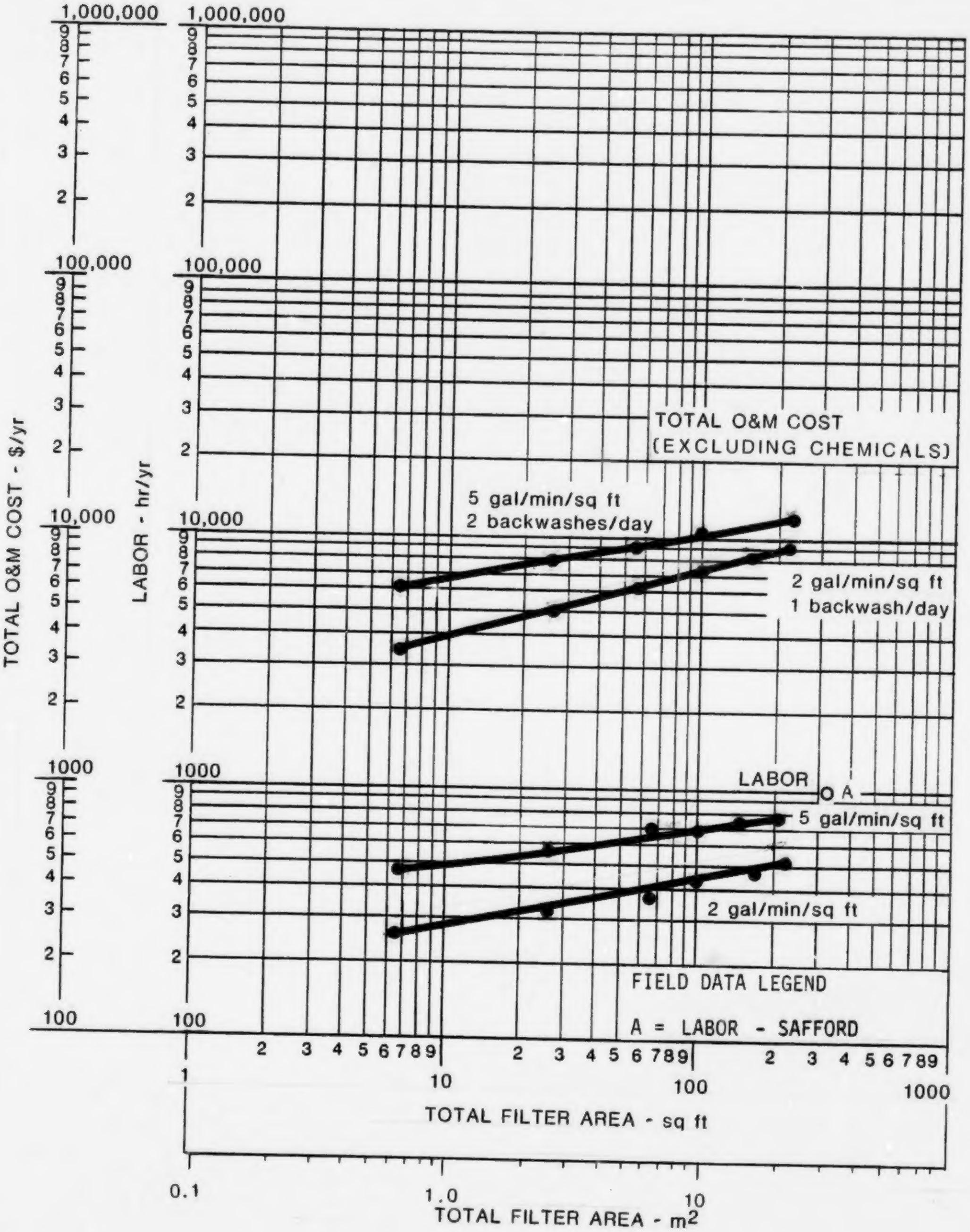


Figure 22. **Operation and maintenance requirements for package gravity filter plants - labor and total O&M cost.**

5B

DIATOMITE FILTRATION

Introduction

Diatomite filtration accomplishes filtration using a layer of diatomite filter aid deposited on a filter septum. The diatomite filter aid is manufactured from diatomaceous earth. The basic components of most diatomite filter installations are:

- Filter vessel - either vacuum or pressure type
- Filter septum
- Precoat pump and precoat slurry tank
- Body feed pump
- Raw water feed pump
- Recirculation pump

Two types of filter vessels which are used are vacuum and pressure. In both, the filter septum is located within the vessel. Vacuum filters are open to the atmosphere, which allows visual inspection and observation, and accessibility for maintenance and septum cleaning. Vacuum is created by the filter discharge pump, which limits the pressure drop across the filter cake to the net positive suction head of the filter pump. The maximum practical pressure drop across a vacuum filter is in the range of 6.1 to 7.3 m (20-24 ft).

In pressure filters, the filter feed is fed under pressure through the filter cake. This allows a larger quantity of water to be filtered per pound of filter aid, and thus longer filter runs. One disadvantage of pressure filters is the requirement to disassemble the filter to reach the filter internals for repair or replacement.

The filter septum, which is located within the filter vessel, is a rigid structure that is permeable to the movement of water. The maximum opening in the filter septum should be 0.0127 cm (0.005 in). The filter septum is usually flat or tubular shaped, and acts as the support media for the filter cake. Usually, metal or plastic are used for construction of the filter septum.

To initiate the filter cycle, a diatomite slurry called the precoat is circulated through the filter. Precoating builds up a thin layer of filter aid on the filter septum. This precoat layer prevents the filter septum from becoming plugged by impurities, gives a low turbidity filtrate at the start of the filter cycle, and facilitates cleaning at the end of the filter cycle. The precoat is prepared using filtered water and diatomite filter aid. Recirculation through the filters is necessary because many of the diatomite particles have smaller openings than the filter septum. Precoating takes 10 to 15 minutes before adequate clarity is obtained in the filtrate and a sufficient precoat is in place. The amount of precoat is usually between 4.5 and 6.8 kg (10 and 15 lb) per 9.29 m^2 (100 sq ft). Precoat slurry concentration should be above 0.3%, or it is difficult to obtain the "crowning" on the filter septum which is necessary for successful filtration.

When sufficient precoat has been added and the precoat filtrate has cleared up, the filter is put on-line by simultaneously opening the line from the filter feed pump and closing the line from the precoat feed pump. Flow through the filter should be continuous without sudden pressure fluctuations. During filtration, a low dosage of diatomite called body feed is added with the filter feed water. The purpose of body feed is to maintain the porosity of the filtering cake during the filter run. If the body feed rate is too low, the diatomite is surrounded by removed turbidity and other materials and the cake permeability is decreased. If, on the other hand, the body feed rate is too high, the cake thickness increases and the permeability decreases, also shortening the filter run. Body feed is provided using either dry feeders or slurry feeders.

When the filter is operated on an intermittent basis, a small recirculation pump is used to provide enough pressure to keep the cake on the filter septum. The recirculation pump has a capacity of 5-10% of the design flow of the filter.

When the filtering cycle is complete, the filter cake must be removed. For vacuum filters, which have an open top, sluicing is usually used. For pressure filters, removal techniques include air-bumping, backwashing, or a combination of the two. The best method(s) for filter cake removal vary between filters, and is generally recommended by the filter manufacturer.

During cake removal, it is essential that the filter septum be completely cleaned, and that the spent cake be removed from the filter. If the septum is not properly cleaned, filter blinding will occur and inadequate filter performance will result.

Impact of Raw Water Quality on Treatment Cost

Raw water quality, principally the turbidity, affects both capital and operation and maintenance cost of vacuum diatomite filters. Generally, low turbidity surface waters of good bacteriological quality can be filtered at higher rates than highly turbid surface waters. This will allow a higher loading rate on the filter, and thereby reduces capital cost. Highly turbid waters often require pretreatment, which increases capital cost.

Operation and maintenance cost increases with turbidity, since higher body feed rates are required. In high turbidity waters, alum or polyelectrolytes may be required as supplements to the filter aid, in order to produce a high clarity filtrate. These additional chemicals further increase operational cost.

PACKAGE VACUUM DIATOMITE FILTERS

Construction Costs

Construction costs were developed for installations using a single vacuum diatomite filter, and filter areas between 2.79 and 66.9 m^2 (30 and 720 sq ft). Figure 23 is a typical installation used to develop construction costs and conceptual design information used in cost development is shown in Table 32. The 2.79 m^2 (30 sq ft) filter shown in Table 32 is the smallest unit commercially available, and is applicable to treatment at rates of 163.5 m^3/d (43,200 gpd) and less.

TABLE 32. CONCEPTUAL DESIGNS FOR PACKAGE VACUUM DIATOMITE FILTERS

Plant Capacity, gpd	Number of Units	Filter Surface Area, sq ft	Filtration Rate, gpm/sq ft	Housing LxWxH, ft	Housing Area, sq ft
43,200	1	30	1	26x10x10	260
172,800	1	120	1	26x12x10	312
259,200	1	180	1	26x14x10	364
518,400	1	360	1	29x18x10	500
1,036,800	1	720	1	28x26x10	728

The construction costs are for a complete installation including filter aid storage, mixing and feeding equipment, vacuum filtration unit, automatic element washer, filter hold and main pumps, filter valves, interconnecting piping, and automatic control panel. The costs also include housing for the equipment, with a 3.05 m (10 ft) ceiling height. Costs for raw water pumping, filtered water storage and high service pumping are not included.

Construction costs are presented in Table 33 and are also shown in Figure 24.

Operation and Maintenance Requirements and Costs

Operating and maintenance requirements were developed from estimates of energy and labor requirements for the conceptual designs presented in Table 32. The information used to develop these requirements was furnished by manufacturers and is representative of minimum operating requirements.

Process electrical energy is for filter pumps, hold pumps, mixers, and other items associated with the filter system. A cycle time of 24 hours between backwashes was assumed in developing electrical requirements. Operation is assumed to be continuous 24 hours per day, 365 days per year. The process energy requirements do not include those associated with raw water or finished water pumping.

TABLE 33. CONSTRUCTION COST SUMMARY FOR PACKAGE VACUUM DIATOMITE FILTERS

Cost Category	Filter Area, sq ft 30	120	180	360	720
Excavation and Sitework	$ 2,800	$ 3,300	$ 3,900	$ 4,800	$ 7,000
Manufactured Equipment	10,800	26,800	29,900	41,200	56,700
Concrete	4,300	4,800	5,600	7,200	10,500
Labor, Installation	2,800	6,900	7,800	10,700	14,700
Pipe and Valves	1,600	5,300	5,900	7,300	9,300
Electrical, Instrumentation	3,600	9,100	10,400	14,100	19,600
Housing	16,100	18,700	21,100	25,000	30,600
Subtotal	42,000	74,900	84,600	110,300	148,400
Design Contingencies	6,300	11,200	12,700	16,600	22,300
Total	$48,300	$86,100	$97,300	$126,900	$170,700

TABLE 34. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE VACUUM DIATOMITE FILTERS

Filter Area, sq ft	Energy, kwh/yr Building	Process	Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
30	3,800	9,700	13,500	200	730	9,200
120	4,500	19,300	23,800	400	910	12,100
180	5,300	32,100	37,400	500	1,100	15,200
360	7,300	48,200	55,500	600	1,500	21,000
720	10,600	64,100	74,700	800	2,900	38,000

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, instrument and chemical feed pump replacement parts, and general facility maintenance supplies. Costs for treatment chemicals are excluded.

Labor requirements were developed assuming that the diatomite filter installation operates automatically and virtually unattended. Operator attention is necessary only for preparation of body feed and precoat, chemical feed adjustment, and measurement of product water quality.

Operation and maintenance requirements are summarized in Table 34 and illustrated in Figures 25 and 26.

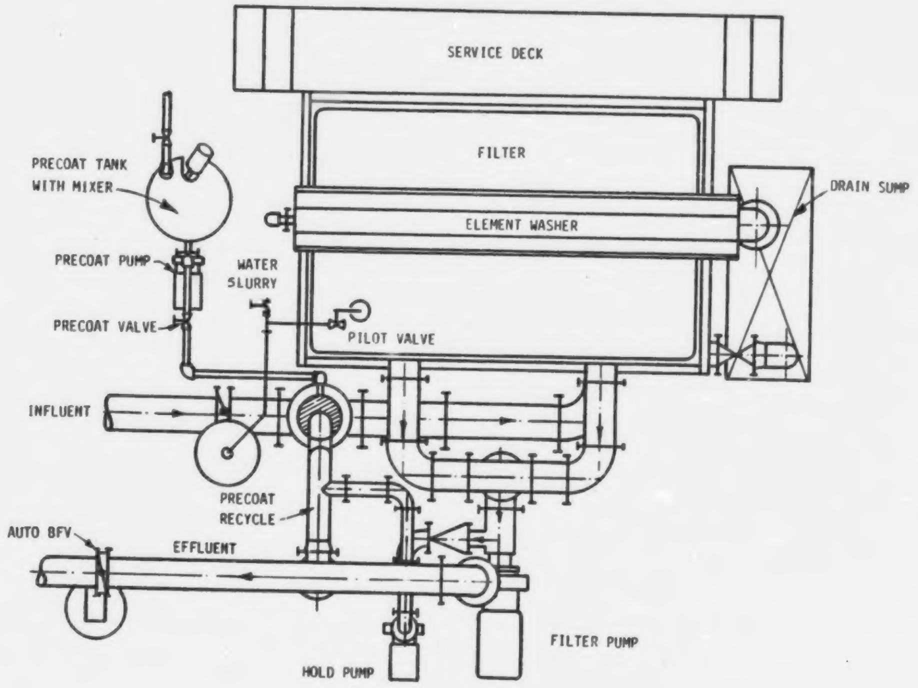
Typical Chemical Requirements and Costs

A "typical" chemical dosage is difficult to establish because of the widely varying characteristics of the raw water supplies. For raw water turbidities of less than 5 NTU (recommended upper limit for application of diatomite filtration) filter aid dosages commonly range between 10 to 30 mg/L including both precoat and body feed. Table 35 presents typical costs for turbidity removal with a vacuum diatomite filter assuming a diatomite dosage of 20 mg/L at a cost of \$0.33 per kg (\$0.15 per lb), and a polyelectrolyte dosage of 0.1 mg/L at a cost of \$6.60 per kg (\$3.00 per lb). Polyelectrolyte is included because it is used to optimize plant performance in some situations.

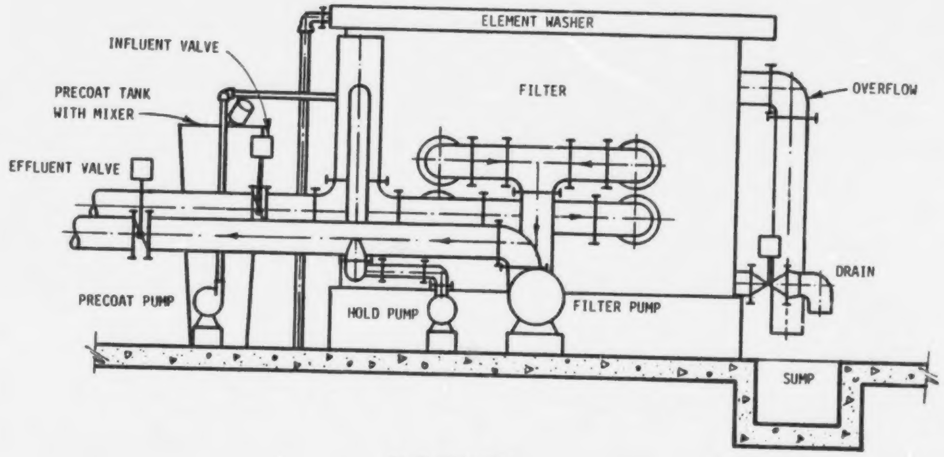
TABLE 35. TYPICAL CHEMICAL COSTS FOR PACKAGE VACUUM DIATOMITE FILTERS

Filter Area, Sq Ft	Plant Flow, gpd	Filter Aid		Polyelectrolyte		Total Chemical Cost, \$/yr
		lb/yr	\$/yr	lb/yr	\$/yr	
30	43,200	2,630	400	13	40	440
120	172,800	10,520	1,600	53	160	1,760
180	259,200	15,780	2,400	79	240	2,640
360	518,400	31,560	4,700	158	470	5,170
720	1,036,800	63,120	9,500	315	950	10,450

Notes: 1. Filter aid dosage is 20 mg/L and includes both precoat and body feed. Polyelectrolyte dosage is 0.1 mg/L.
2. Filter aid cost is \$0.15/lb and polyelectrolyte cost is \$3.00/lb.
3. Plant operation is 24 hours/day, 365 days/year.


SERVICE DECK
FILTER
PRECOAT TANK WITH MIXER
DRAIN SUMP
ELEMENT WASHER
PRECOAT PUMP
WATER SLURRY
PRECOAT VALVE
PILOT VALVE
INFLUENT
PRECOAT RECYCLE
AUTO BFV
EFFLUENT
FILTER PUMP
HOLD PUMP

PLAN


ELEMENT WASHER
INFLUENT VALVE
PRECOAT TANK WITH MIXER
FILTER
OVERFLOW
EFFLUENT VALVE
DRAIN
PRECOAT PUMP
HOLD PUMP
FILTER PUMP
SUMP

ELEVATION

Figure 23. **Typical package vacuum diatomite filter installation**

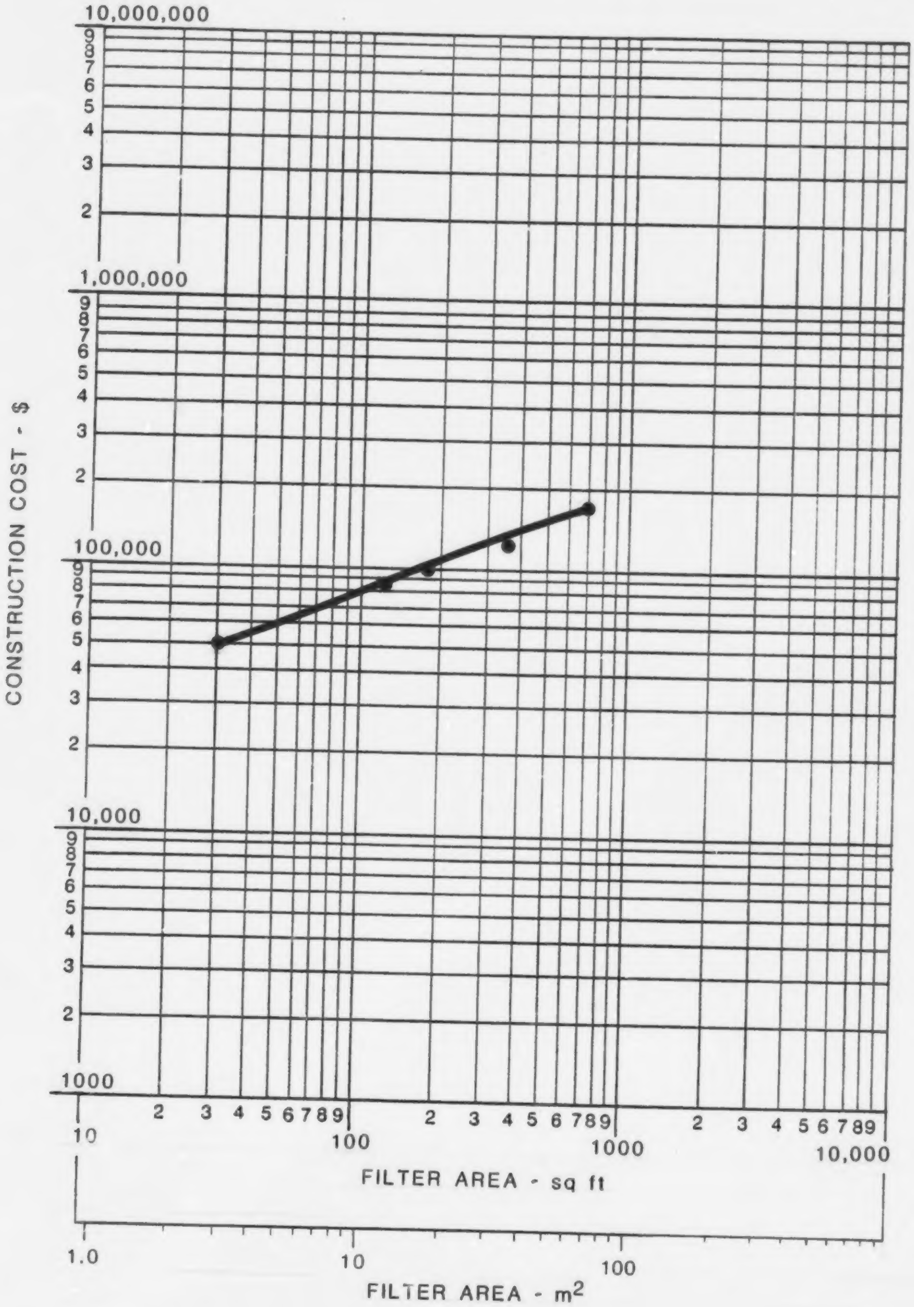


Figure 24. Construction cost for package vacuum diatomite filters.

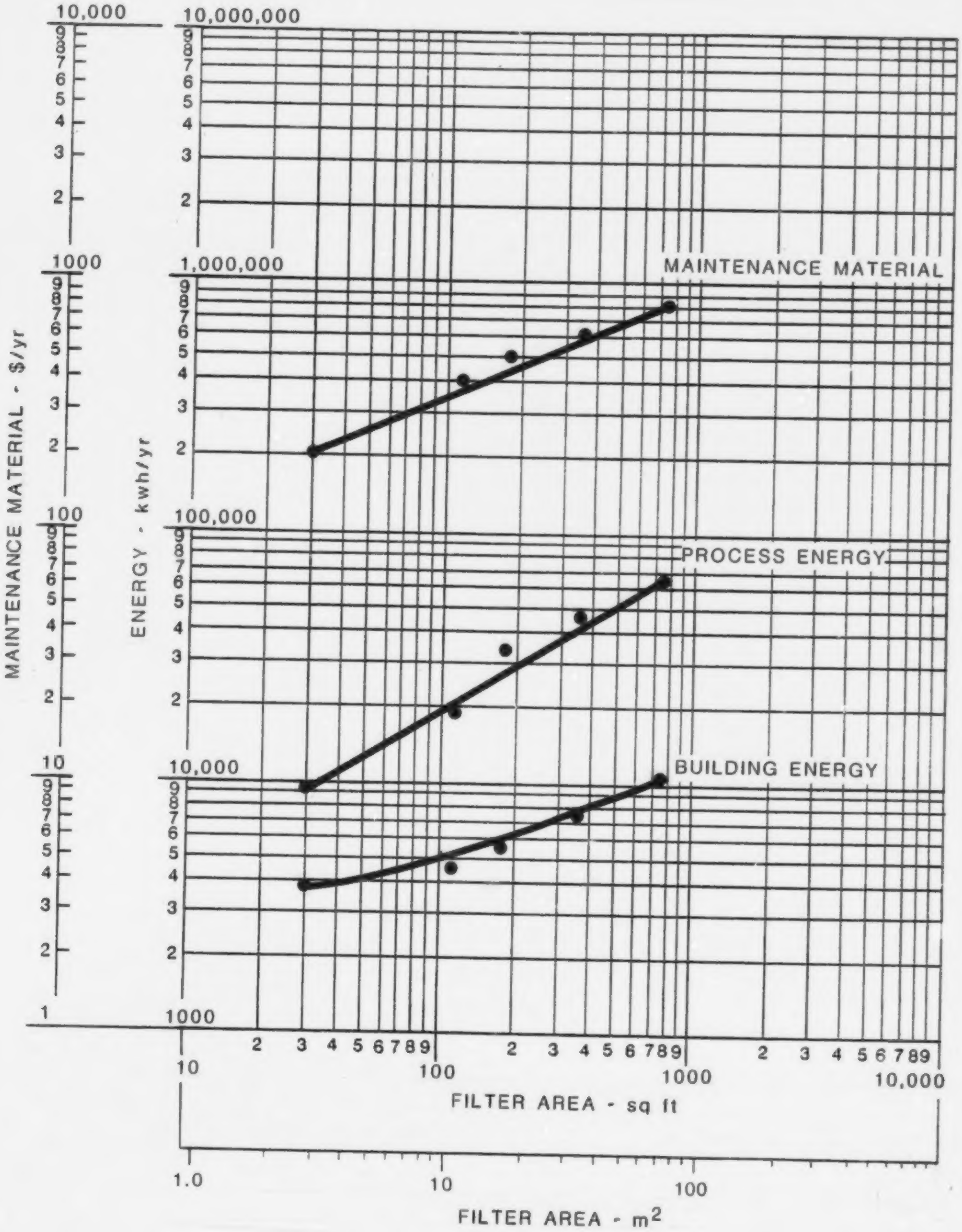


Figure 25. **Operation and maintenance requirements for package vacuum diatomite filters - building energy, process energy, and maintenance material.**

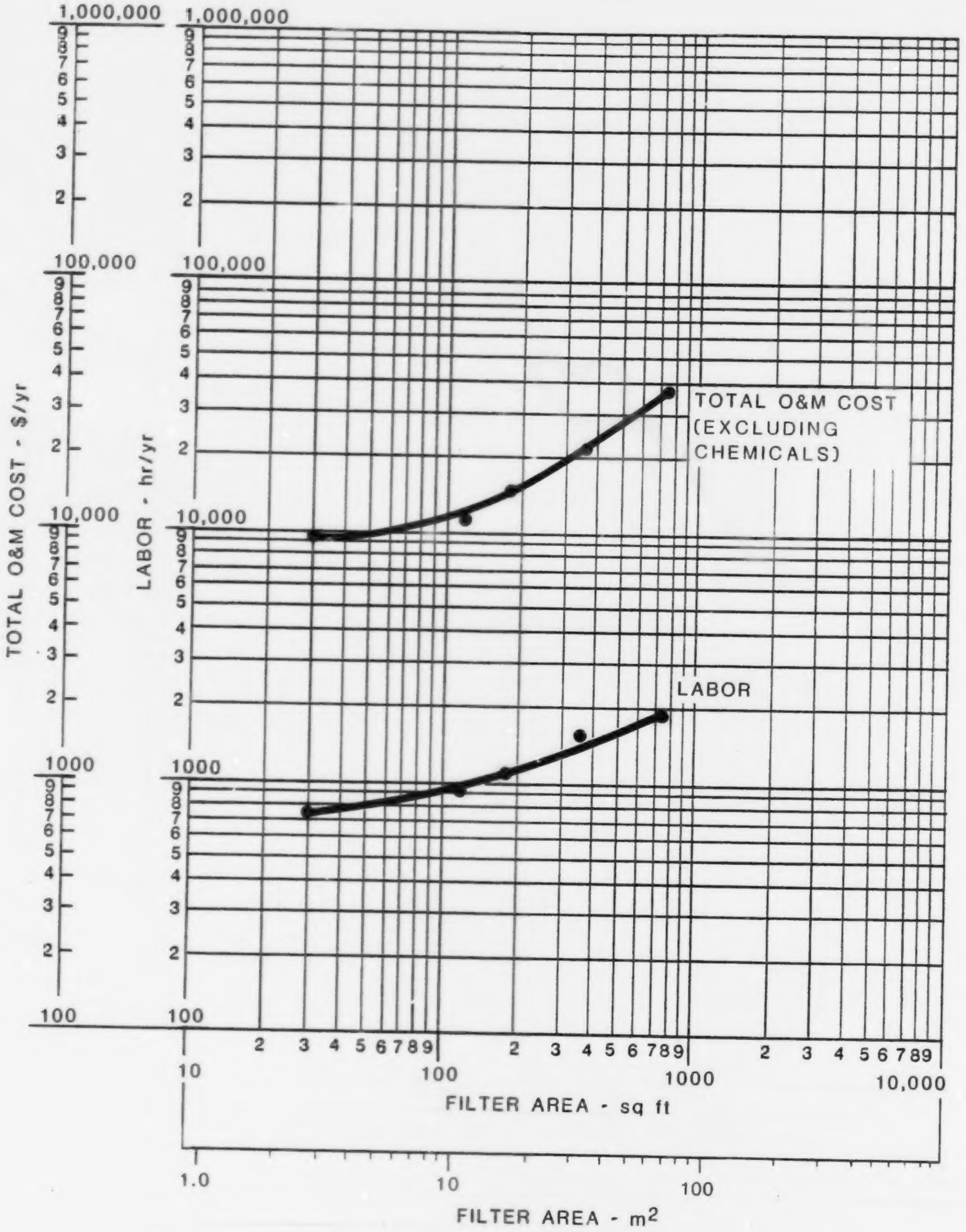


Figure 26. **Operation and maintenance requirements for package vacuum diatomite filters - labor and total O&M cost.**

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PACKAGE PRESSURE DIATOMITE FILTERS

Construction Costs

Construction costs were developed for a series of diatomaceous earth filter installations with filter areas between 1.78 and 69.7 m^2 (19.2 and 750 sq ft). The conceptual designs used to develop these construction costs are presented in Table 36. The smallest unit shown in Table 36 would be used for a plant capacity of 106 m^3/d (28,000 gpd) and less, as it is the smallest practical size. A filtration rate of approximately 2.44 $m^3/m^2/h$ (1 gpm/sq ft) of filter area, in accordance with standard industry practice, was used to establish filter size. The cost estimates are for a complete installation, including diatomaceous earth storage, preparation and feed facilities, pressure filtration units, filter supply pump, filter valves, interconnecting pipe and fittings, and control panel for automatic operation. Housing costs were developed assuming total enclosure of the filters with minimum additional space for access on all sides of the filter units for maintenance. Figure 27 is an illustration of a typical pressure diatomite filter installation.

TABLE 36. CONCEPTUAL DESIGNS FOR PACKAGE PRESSURE DIATOMITE FILTERS

Plant Capacity, gpd	No. of Units	Tank Diameter, inches	Filter Surface Area, sq ft	Filtration Rate, gpm/ft	Housing LxWxH, ft	Housing Area, sq ft
28,000	1	16	19.2	1	26x10x10	260
86,000	1	24	55	1	28x10x10	280
140,000	1	36	102	1	30x12x10	360
280,000	1	42	202	1	30x15x10	450
580,000	2	42	404	1	35x15x10	525
1,000,000	3	48	750	1	45x18x10	810

Construction costs are presented in Table 37 and Figure 28.

Operation and Maintenance Requirements and Costs

Process energy is for filter feed pumps, precoat feed pump, body feed pump, mixers, and other items associated with the filter system. A cycle time of 24 hours between cake removal was assumed in developing electrical requirements. The energy requirements do not include those associated with raw water or finished water pumping.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, chemical feed pump replacement parts, and general facility maintenance supplies. Maintenance material cost estimates were furnished by manufacturers and are based on experience at many plants. Costs for treatment chemicals, including diatomaceous earth are not included in maintenance materials, but are discussed in a subsequent section.

TABLE 37. CONSTRUCTION COST SUMMARY FOR PACKAGE PRESSURE DIATOMITE FILTERS

Cost Category	Filter Area, sq ft 19.2	55	102	202	404	750
Excavation and Sitework	$ 2,800	$ 3,000	$ 3,800	$ 4,800	$ 5,000	$ 7,800
Manufactured Equipment	16,300	21,700	35,600	47,000	87,600	155,500
Concrete	4,000	4,300	5,500	7,000	8,100	11,600
Labor, Installation	5,000	6,700	11,100	14,600	27,700	48,300
Pipe and Valves	3,800	5,500	7,500	8,300	13,800	17,700
Electrical, Instrumentation	3,900	5,700	9,000	12,500	18,600	23,600
Housing	16,100	11,400	20,900	23,400	25,200	32,400
Subtotal	51,900	58,300	93,400	117,600	186,000	296,900
Design Contingencies	7,800	8,800	14,000	17,600	27,900	44,500
Total	$59,700	$67,100	$107,400	$135,200	$213,900	$341,400

Labor requirements were developed assuming that the diatomite filter installation operates automatically. Operator attention is necessary only for preparation of body feed and precoat, and for verification that chemical dosages are proper and that the equipment is producing a satisfactory quality filtered water.

Operation and maintenance requirements are summarized in Table 38 and are illustrated in Figures 29 and 30.

TABLE 38. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE PRESSURE DIATOMITE FILTERS

Filter Area, sq ft	Energy, kwh/yr Building	Process	Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
19.2	3,800	1,400	5,200	200	700	8,300
55	4,100	4,200	8,300	300	750	9,100
102	5,200	6,900	12,100	400	900	11,200
202	6,600	13,800	20,400	500	1,100	14,100
404	7,600	27,600	35,200	700	1,500	19,700
750	11,800	51,800	63,600	900	2,900	37,300

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

A "typical" chemical dosage is difficult to establish because of the widely varying characteristics of the raw water supplies. For raw water turbidities of less than 5 NTU (recommended upper limit for application of diatomite filtration) filter aid dosages commonly range between 10 to 30 mg/L including both precoat and body feed. Table 39 presents typical costs for turbidity removal with a pressure diatomite filter assuming a diatomite dosage of 15 mg/L at a cost of $0.33/kg ($0.15 per lb).

TABLE 39. TYPICAL CHEMICAL COSTS FOR PACKAGE PRESSURE DIATOMITE FILTERS

Filter Area, sq ft	Plant Flow Rate, gpd	Filter Aid	
		lb/yr	$/yr
19.2	28,000	1,280	190
55	86,000	3,930	590
102	140,000	6,390	960
202	280,000	12,790	1,900
404	580,000	26,480	4,000
750	1,000,000	45,660	6,800

Notes: 1. Filter aid dosage is 15 mg/L and includes both precoat and body feed.
2. Filter aid cost is $0.15/lb.
3. Plant operation is 24 hours/day, 365 days/year.

Field Data Collection

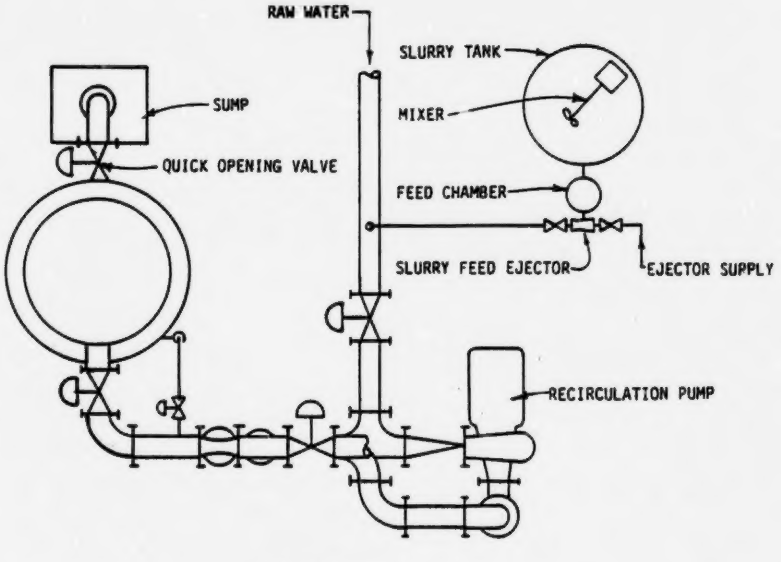
Field operating data was collected at two locations where pressure diatomaceous earth filtration was being utilized. These locations were Rialto, California, and Rouses Point, New York. At Rialto, the design capacity was 5,299 m^3/d (1.4 mgd), the operating flow rate was 4,341 m^3/d (1.147 mgd), and the total filter area was 71.07 m^2 (765 sq ft).

At Rouses Point, two types of diatomaceous earth filters were utilized. Older units used a dacron cloth filter media over stainless steel, and newer units used porous stone. The surface area of these filters was not obtained by the field investigator. However, based upon a total design capacity of 8,516 m^3/d (2.25 mgd) and a filtration rate of 2.44 m^3/d (1 gpm/sq ft), a total filter area of 145.1 m^2 (1,563 sq ft) is estimated.

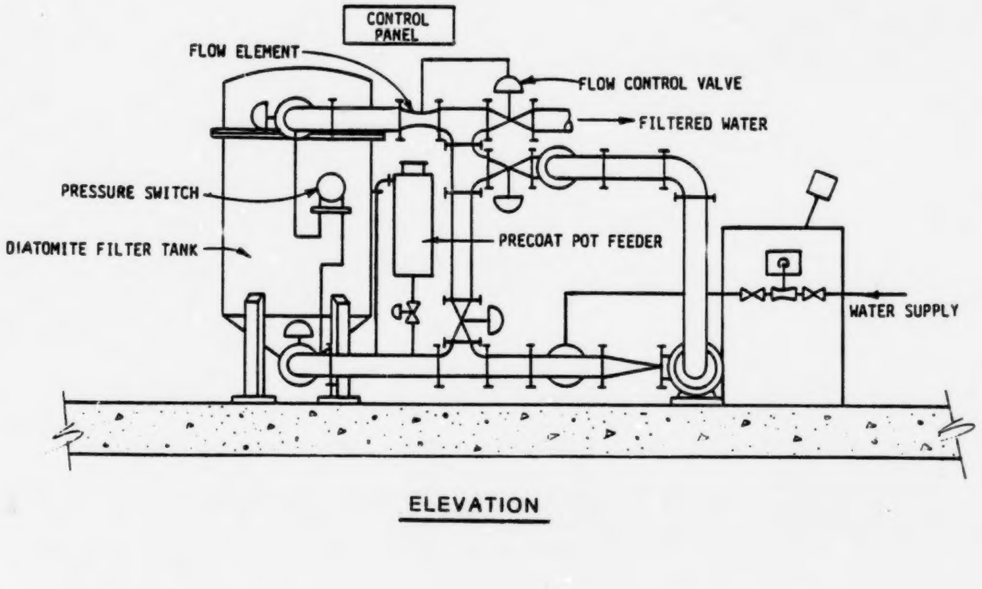
A comparison of field operating data and Figures 29 and 30 is shown following:

	Rialto		Rouses Point	
	Field Data	Data From Figures 29 and 30	Field Data	Data From Figures 29 and 30
Electrical Energy, kwh/hr				
Process	-	55,000	-	100,000
Building	-	12,000	-	16,000
Total	196,800	67,000	693,200	116,000
Maintenance Material, $/yr	2,270	900	2,720	1,300
Labor, hr/yr	509	2,800	5,052	4,500

There is no apparent explanation for the discrepancy in electrical requirements at Rialto. At Rouses Point, however, electrical requirements for both raw water and product water pumping are included in the field data, which results in higher values than Figure 29. Labor is low at Rialto, according to the utility, because the plant is highly automated.


RAW WATER
SLURRY TANK
MIXER
SUMP
QUICK OPENING VALVE
FEED CHAMBER
SLURRY FEED EJECTOR
EJECTOR SUPPLY
RECIRCULATION PUMP

PLAN


CONTROL PANEL
FLOW ELEMENT
FLOW CONTROL VALVE
FILTERED WATER
PRESSURE SWITCH
PRECOAT POT FEEDER
DIATOMITE FILTER TANK
WATER SUPPLY

ELEVATION

Figure 27. Typical package pressure diatomite filter installation.

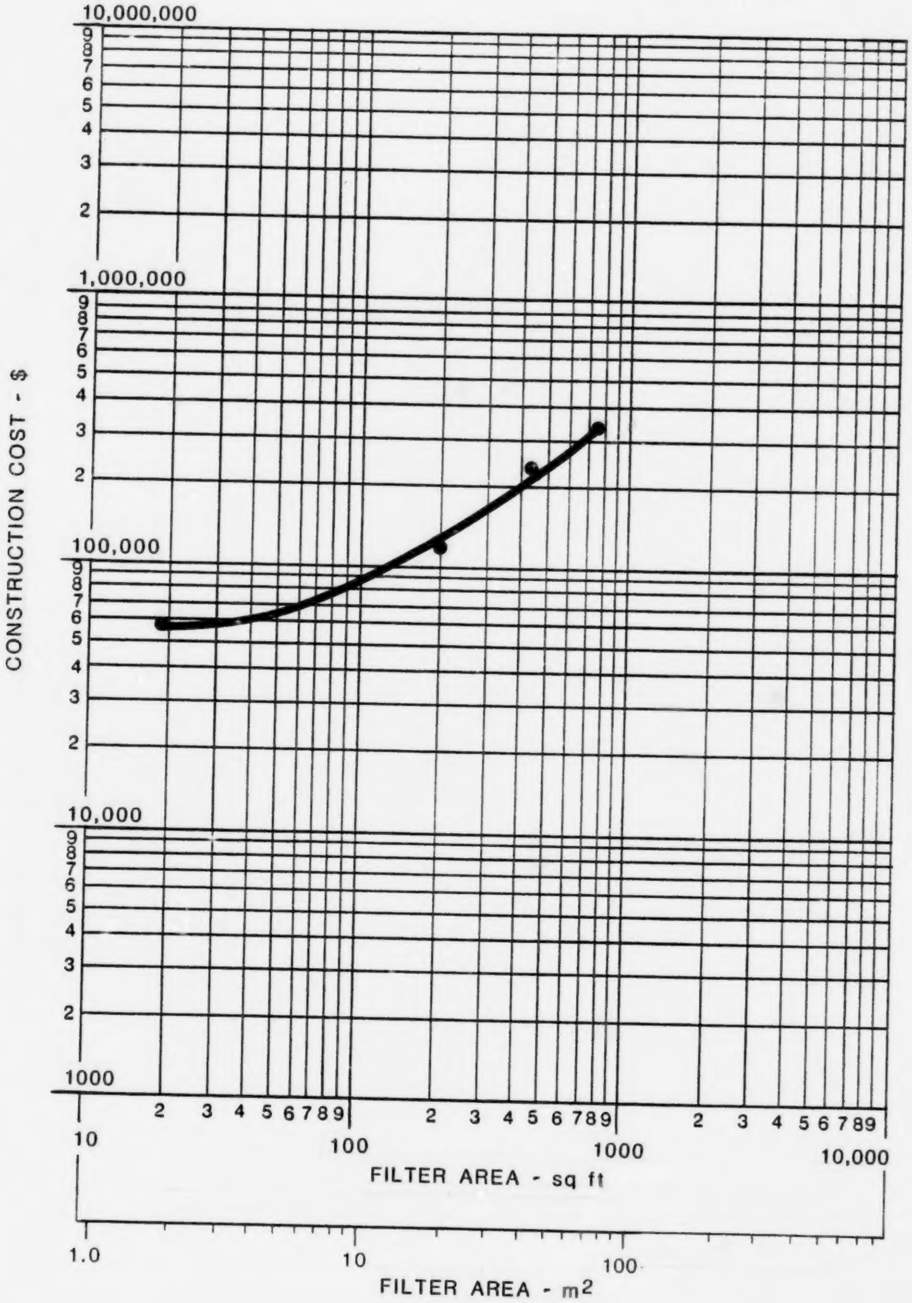


Figure 28. **Construction cost for package pressure diatomite filters.**

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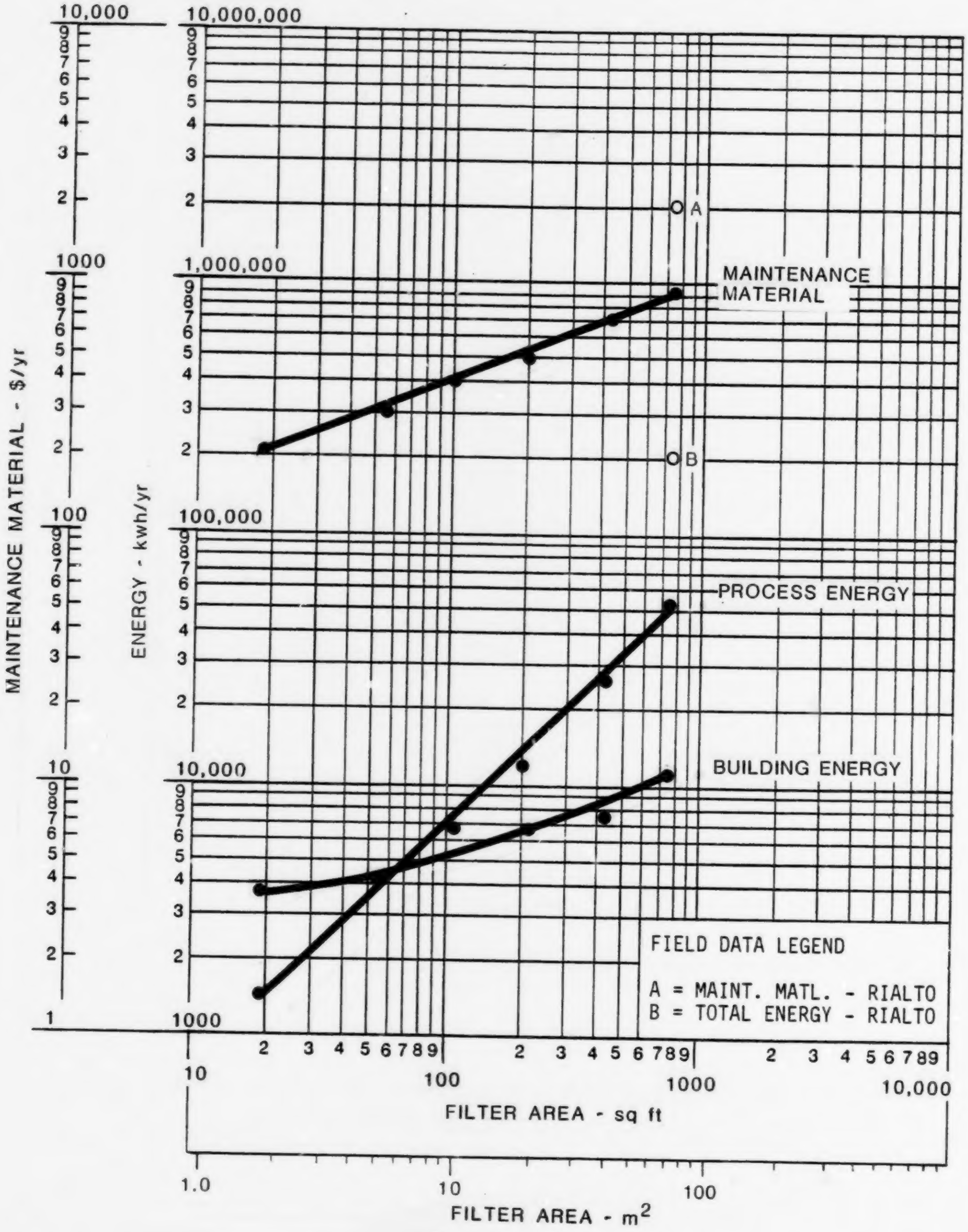

Figure 29. Operation and maintenance requirements for package pressure diatomite filters - building energy, process energy, and maintenance material.

10A

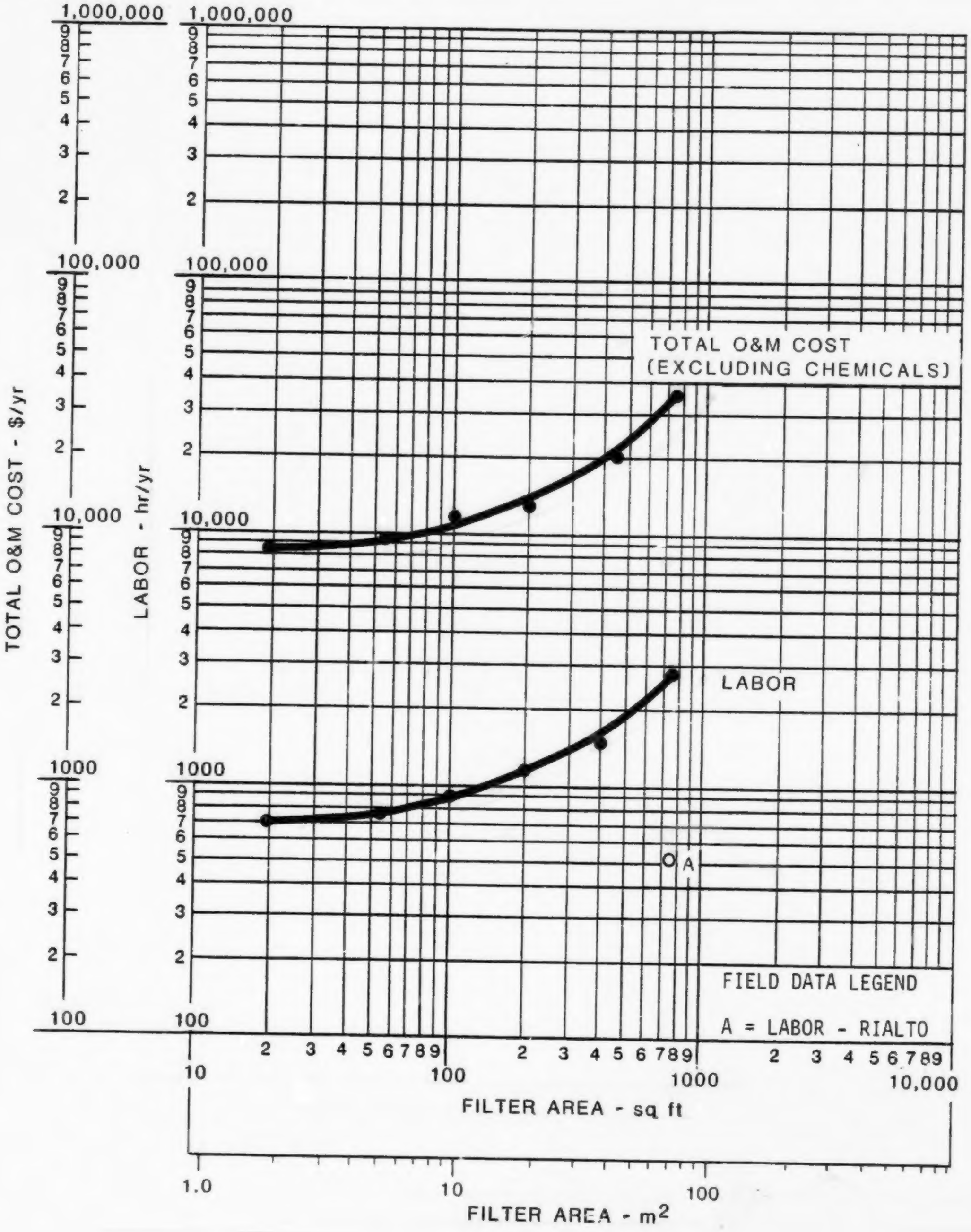

Figure 30. **Operation and maintenance requirements for package pressure diatomite filters - labor and total O&M cost.**

SLOW SAND FILTERS

Introduction

Slow sand filters are used to remove turbidity and pathogenic microorganisms. There are several operative removal mechanisms during slow sand filtration. First, as the water enters the filter, it is held for a number of hours above the sand bed, allowing the heavier suspended particles to settle to the surface of the filter. On the surface of the sand, a thin, slimy matting of organic material called the Shmutzdecke is formed, through which the water must pass. The Shmutzdecke provides contaminant removal both by biological means as well as physical means (straining). The water then passes through the sand bed where due to straining and adsorption onto the sand particle surfaces, additional contaminant removal takes place. The product water is usually of low turbidity and good bacteriological quality.

As the name implies, the key to the performance of a slow sand filter is the very low filtration rate. Rates listed in the literature (References 1-5) range from 0.94 to 9.38 $m^3/d/m^2$ (23 to 230 gpd/sq ft) with 2.86 $m^3/d/m^2$ (70 gpd/sq ft) being a common value. This rate is approximately 100 times slower than a rapid sand filter and thus a comparable capacity slow sand filter will require from 50 to 100 times the area of a rapid filter. Recommended sand bed depths range from 0.6 to 1.4 m (2.0 to 4.6 ft) with 1.07 to 1.22 m (3.5 to 4.0 ft) being the most popular, and recommended water supernatant depths range from 1.0 to 1.25 m (3.3 to 4.1 ft).

Costs are presented in this section for two types of slow sand filters. One type is a cast-in-place, concrete covered structure, and the other is an uncovered earthen berm structure. Although covered filters have a higher construction cost, they have several advantages: no freezing problems during winter months; no algae growth in the water above the filter; and no problems resulting from windblown debris or bird droppings. Conversely, uncovered filters have lower capital costs. Disadvantages of uncovered filters are high berm maintenance requirements, algae growth in the water above the filter bed, and potential contamination by windblown debris and bird droppings. The construction costs for the uncovered filter were kept to the minimum by the use of low cost material and the elimination of equipment not absolutely essential for operation of the filters. Thus, the uncovered filters are representative of the most economical design consistent with reliable operation. Conversely, the covered filters include a number of items not included in the uncovered filters, such as steel pipe instead of PVC pipe and an effluent flow meter on each filter. Overall, the covered filters are representative of a conventionally designed facility, and should provide more reliable operation over the long-term than the more economically designed uncovered filters.

The costs in this section are not necessarily for a complete plant. In most cases, chlorination facilities would need to be included; additionally, many situations may require raw water pumping facilities.

Impact of Raw Water Quality on Treatment Cost

The principal water quality characteristic of concern is turbidity. Turbidity not only increases the cost of treatment, but may exclude the use of slow sand filters if too high. The literature (1, 2, & 5) recommends the turbidity be no higher than 30 NTU* to 50 NTU** with 10 NTU* being the ideal level. Turbidity may impact capital costs by requiring a lower filtration rate and thus larger filters to accommodate a given flow. The more likely impact, however, is on operation and maintenance costs. Higher turbidities will necessitate more frequent filter bed cleanings.

Construction Costs

As indicated on the previous page, construction costs were developed for two types of structures: a cast-in-place concrete structure which provides for covered filters and an uncovered earthen berm structure. Table 40 presents the the criteria upon which both types of slow sand filters were based.

TABLE 40. DESIGN CRITERIA FOR SLOW SAND FILTERS

Criteria	Values
Filtration Rate	70 gpd/sq ft
Depth of Sand	3.5 ft
Depth of Support Gravel	1 ft
Supernatant Box Depth	4.0 ft
Clear Water Storage	12 hours production

Table 41 presents design capacities, filter areas, and reservoir capacities used in the cost estimates. It was assumed that one extra filter was necessary for firm capacity.

Covered Slow Sand Filters--

Figure 31 is a schematic of the covered slow sand filter, and illustrates what components are included in the construction costs. The concept of the covered filters incorporates below-grade concrete structures with beam and slab covers. All piping is either cast iron or steel and is also below grade.

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*Reference 5 reports turbidity in units of ppm. An approximate relationship of 1 ppm = 1 NTU is assumed for comparative purposes.

**Reference 1 reports turbidity in units of mg/L. An approximate relationship of 1 mg/L = 1 NTU is assumed for comparative purposes.

TABLE 41. CONCEPTUAL DESIGNS FOR SLOW SAND FILTERS

Plant Capacity, gpd	Number of Filters	Capacity Per Filter, gpd	Filter Area, sq ft		Housing		Clear Water Reservoir Capacity, gal
			Total	Per Filter	LxWxH, ft	Area, sq ft	
50,000	3	25,000	1,080	360	20x20x10	400	25,000
100,000	3	50,000	2,160	720	25x20x10	500	50,000
200,000	4	67,000	3,840	960	30x20x10	600	100,000
500,000	6	100,000	8,580	1,430	35x20x10	700	250,000
1,000,000	8	140,000	16,000	2,000	32x25x10	800	500,000

Because slow sand filters operate most efficiently at a constant filtration rate, flow meters for each filter and a below-grade, concrete clear water reservoir are included. The rate of flow through the filter is established by an individual control valve for each filter. Also included in the concept is an effluent flow control structure. This structure has two principal purposes: (1) to prevent the water level in the sand filter from inadvertently being drawn down below the filter surface; and (2) to aerate the filter effluent to release any odors which may be present. Table 42 and Figure 33 present construction costs for covered slow sand filters. Included in these costs is excavation to allow these structures to be constructed below grade as indicated on Figure 31, a pump to allow backfilling of filters after cleaning, and a clear water reservoir.

TABLE 42. CONSTRUCTION COST SUMMARY FOR COVERED SLOW SAND FILTERS

Cost Category	Total Filter Area, sq ft				
	1,080	2,160	3,840	8,580	16,000
Excavation and Sitework	$ 12,400	$ 24,800	$ 46,800	$ 74,100	$ 123,000
Manufactured Equipment	25,200	41,600	57,100	113,000	202,000
Concrete*	52,900	91,900	125,000	281,000	534,000
Labor, Installation	66,200	110,000	147,000	314,000	585,000
Pipe and Valves	11,100	21,100	28,300	44,000	65,000
Electrical, Instrumentation	18,400	29,400	40,600	80,000	142,200
Housing	22,000	25,000	27,600	29,400	32,000
Subtotal	208,200	343,800	472,400	935,500	1,683,200
Design Contingencies	31,200	51,600	70,900	140,300	252,500
Total	$239,400	$395,400	$543,300	$1,075,800	$1,935,700

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*Includes gravel, sand, and drain tile.

Uncovered Slow Sand Filters--

Figure 32 is a schematic of an uncovered slow sand filter and illustrates components included in the construction costs. The concept of the uncovered filters incorporates on-grade, clay-line structures formed by earthen berms All piping is PVC and is below grade. A steel tank reservoir, an effluent flow control structure, a single flow meter to measure total plant flow, and a pump for filter backfilling are also included. Table 43 presents the construction costs for uncovered slow sand filters, which are shown in Figure 33.

TABLE 43. CONSTRUCTION COST SUMMARY FOR UNCOVERED SLOW SAND FILTERS

Cost Category	Total Filter Area, sq ft				
	1,080	2,160	3,840	8,580	16,000
Excavation and Sitework*	$ 12,200	$ 17,700	$ 24,700	$ 33,500	$ 43,300
Manufactured Equipment**	82,000	102,000	122,000	153,000	298,000
Concrete***	9,000	12,200	17,100	28,400	43,600
Labor, Installation	14,800	23,900	35,400	63,700	101,000
Pipe and Valves	3,500	6,700	8,300	16,000	23,800
Electrical, Instrumentation	8,400	10,600	13,900	19,900	31,500
Housing	22,000	25,000	27,600	29,400	32,000
Subtotal	151,900	198,100	249,000	343,900	573,200
Design Contingencies	22,800	29,700	37,400	51,600	86,000
Total	$174,700	$227,800	$286,400	$395,500	$659,200

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*Includes berms.

**Represents cost of steel storage tank and backfilling pump.

***Includes clay, sand, and gravel.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements for slow sand filters are usually minimal. The only periodic adjustment required is that of a control valve, to maintain the desired flow through the filter in response to the increasing headloss through the filter. Sand bed cleaning, and berm maintenance for the uncovered slow sand filter, are the only major maintenance tasks. Manual sand bed cleaning is assumed. Maintenance material includes replacement parts associated with filter operation and sand cleaning. Sand replacement cost is not included. Addition of a mechanical sand bed scraper would increase the capital costs by 3 to 13 percent and correspondingly decrease operation and maintenance costs by 8 to 26 percent depending, upon plant size.

Process energy requirements includes only the backfilling pump, which because of the infrequent use of the pump are negligible. Building energy requirements are for heating, lighting, and ventilation of the control and storage building. The fuel requirement is for the mechanical sand bed cleaner and berm maintenance equipment.

Maintenance material requirements were estimated from anticipated costs of replacement parts and replenishment of the minor amount of consumable supplies involved in daily operation. The cost of replacement sand is not included. Experience from operating filters suggests that careful cleaning allows resanding to be necessary as infrequently as every 10 years.

Labor requirements were developed assuming the filters operate unattended. They include a short daily inspection and control valve adjustment, daily turbidity measurements, quarterly cleanings of each filter by hand, normal repair and replacement of equipment and berm maintenance for the uncovered filters. No allowance for administrative or laboratory work is included.

Tables 44 and 45 present the operation and maintenance requirements and costs for covered and uncovered slow sand filters.

TABLE 44. OPERATION AND MAINTENANCE SUMMARY FOR COVERED SLOW SAND FILTERS

Total Filter Area, sq ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
1,080	24,400	-	24,400	1,000	270	5,700
2,160	30,500	-	30,500	1,800	310	7,400
3,840	36,600	-	36,600	2,700	450	10,200
8,580	42,700	-	42,700	4,700	730	15,700
16,000	48,800	-	48,800	8,200	1,120	24,000

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 45. OPERATION AND MAINTENANCE SUMMARY FOR UNCOVERED SLOW SAND FILTERS

Total Filter Area, sq ft	Energy, kwh/yr			Fuel, gal/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total				
1,080	24,400	-	24,400	40	400	320	5,700
2,160	30,500	-	30,500	50	500	370	6,800
3,840	36,600	-	36,600	80	600	530	9,100
8,580	42,700	-	42,700	100	900	840	13,300
16,000	48,800	-	48,800	120	1,500	1,250	18,800

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor, and fuel at $1.10 gal.

Field Data Collection

Operating data was collected on a covered slow sand filter installation at Port Henry, New York. The filter has a total area of 306.6 m^2 (3,300 sq ft). At this plant, sand is removed manually using a wet pumping operation, and washed sand is conveyed back to the filter bed in a sand-water slurry. The filters are cleaned once a year.

A comparison of field operating data with the requirements presented in Figures 34 and 35 is shown following:

	Field Data	Data From Figures 34 and 35
Electrical Energy, kwh/hr		
Process	-	-
Building	-	33,000
Total	-	3,300
Maintenance Material, $/yr	50	2,000
Labor, hr/yr	1,912	330

At this utility, building heating is with propane, and thus there is no building electrical energy requirement. Actual labor requirements are believed to be high because of the labor intensive sand washing operation, which requires multiple handling of the sand. There is no apparent explanation for the difference in maintenance material cost.

References

1. Huisman, L. and Wood, W.E., "Slow Sand Filtration," World Health Organization, 1974.

2. Paramasivam, R. et al., "Slow Sand Filter Design and Construction in Developing Countries," Journal AWWA, Vol. 73, pp. 178, 1981.

3. U.S. EPA, "Manual of Individual Water Supply Systems," EPA-430/9-74-007, 1974.

4. Fair, G.M. and Geyer, J.C., "Water Supply and Waste-Water Disposal," John Wiley & Sons, 1954.

5. Salvato, J.A., "Environmental Sanitation," John Wiley & Sons, 1958.

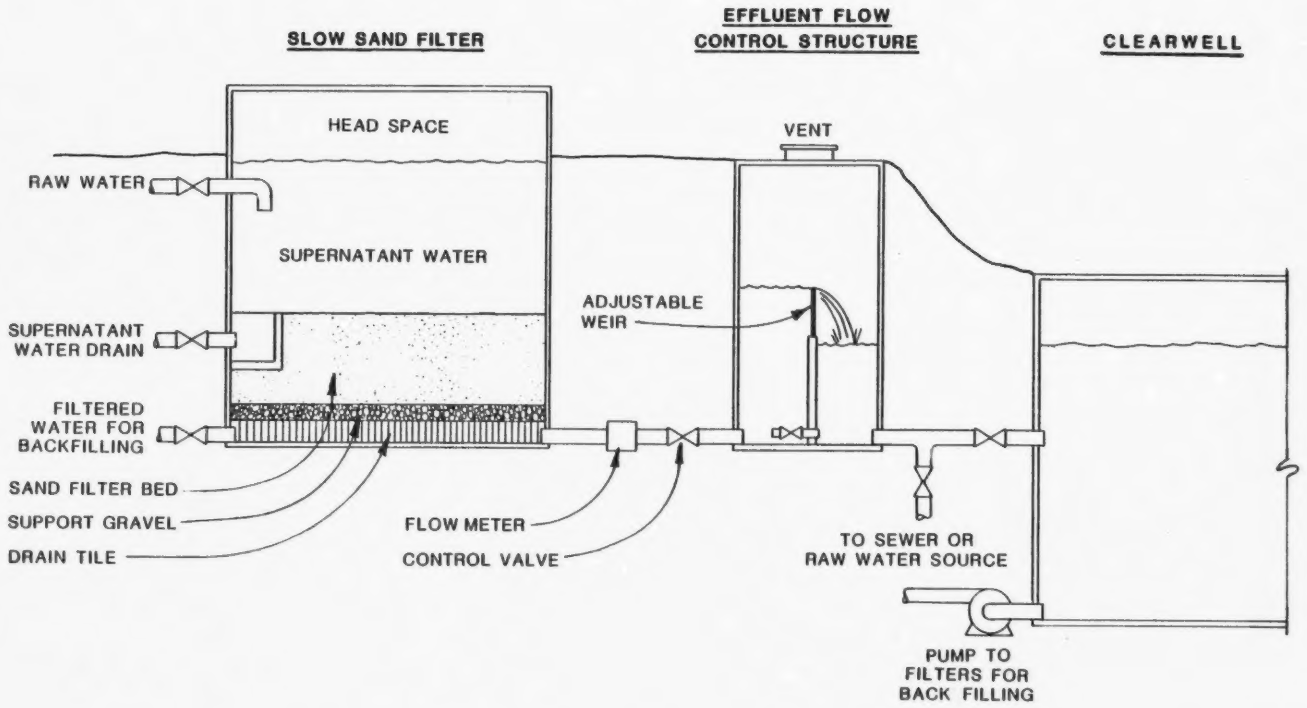

SLOW SAND FILTER
EFFLUENT FLOW CONTROL STRUCTURE
CLEARWELL
HEAD SPACE
VENT
RAW WATER
SUPERNATANT WATER
ADJUSTABLE WEIR
SUPERNATANT WATER DRAIN
FILTERED WATER FOR BACKFILLING
SAND FILTER BED
SUPPORT GRAVEL
DRAIN TILE
FLOW METER
CONTROL VALVE
TO SEWER OR RAW WATER SOURCE
PUMP TO FILTERS FOR BACK FILLING

Figure 31. Typical covered slow sand filter installation.

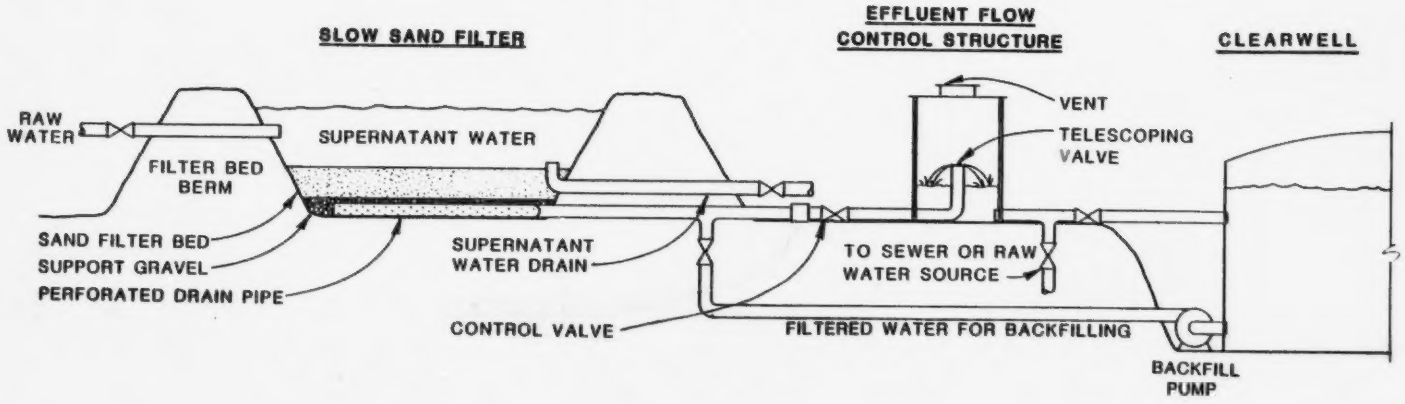

SLOW SAND FILTER
EFFLUENT FLOW CONTROL STRUCTURE
CLEARWELL
RAW WATER
SUPERNATANT WATER
FILTER BED BERM
VENT
TELESCOPING VALVE
SAND FILTER BED
SUPPORT GRAVEL
PERFORATED DRAIN PIPE
SUPERNATANT WATER DRAIN
TO SEWER OR RAW WATER SOURCE
CONTROL VALVE
FILTERED WATER FOR BACKFILLING
BACKFILL PUMP

Figure 32. Typical uncovered slow sand filter installation.

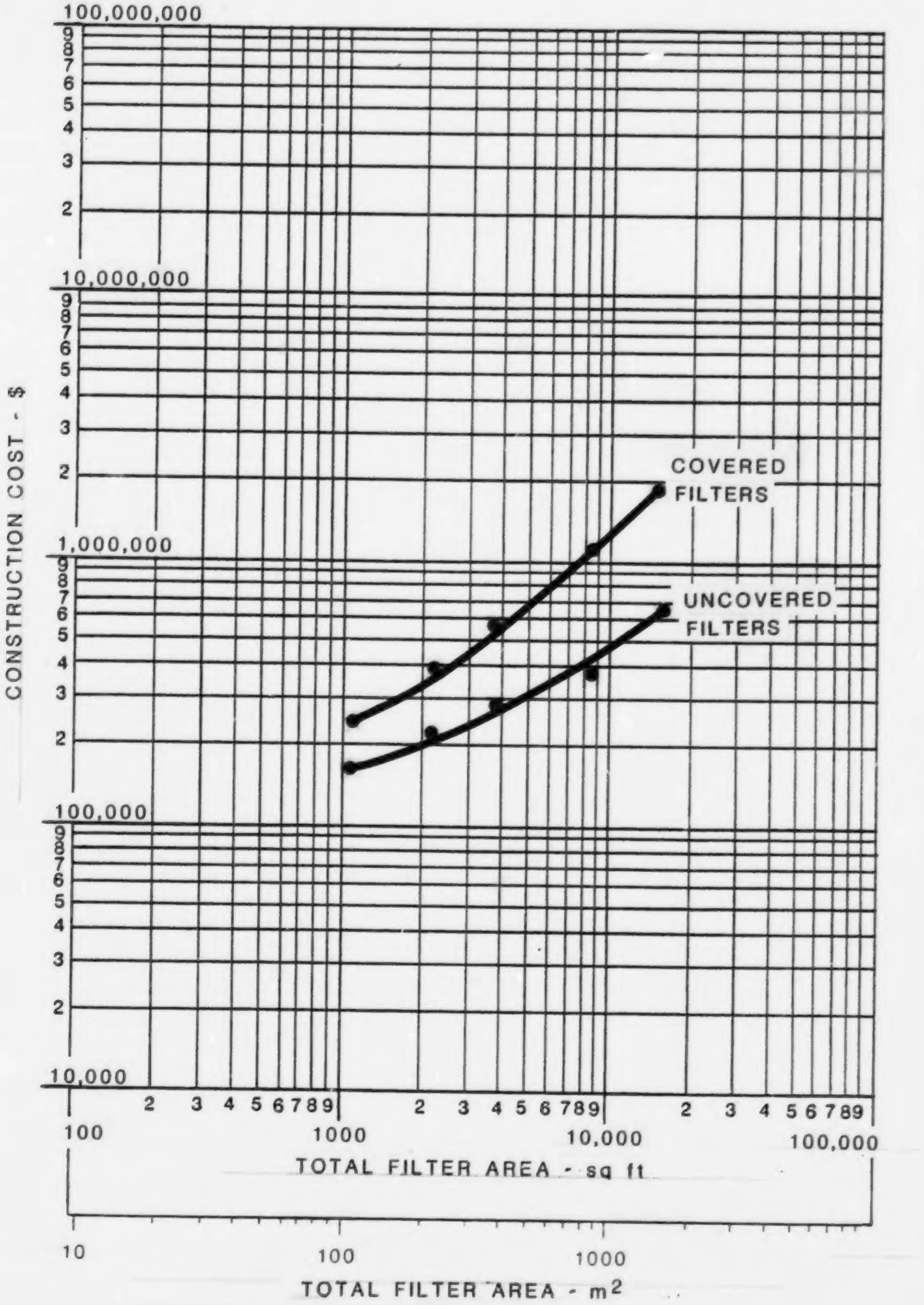


Figure 33. Construction cost for covered and uncovered slow sand filters.

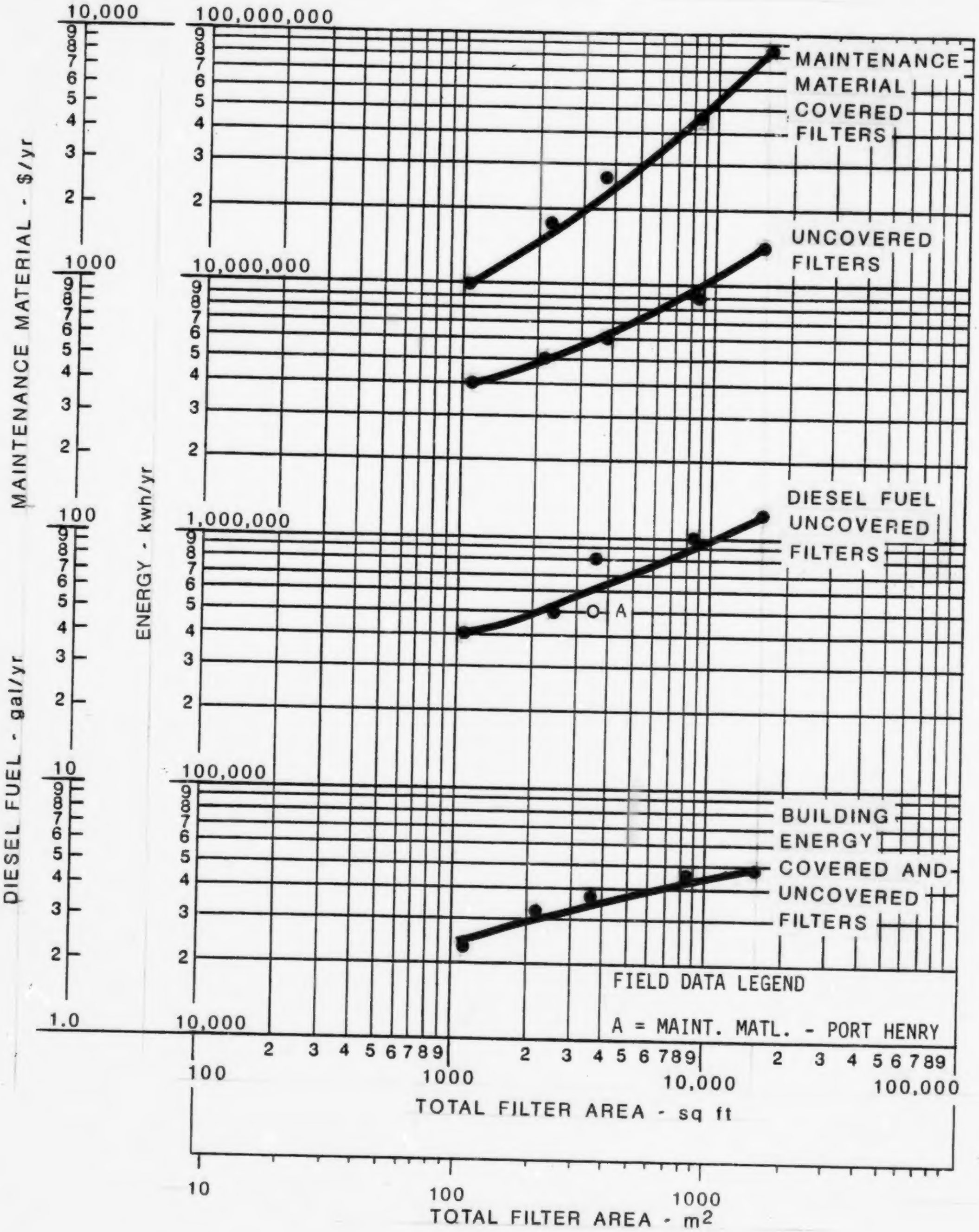


Figure 34. Operation and maintenance requirements for covered and uncovered slow sand filters - building energy, diesel fuel, and maintenance material.

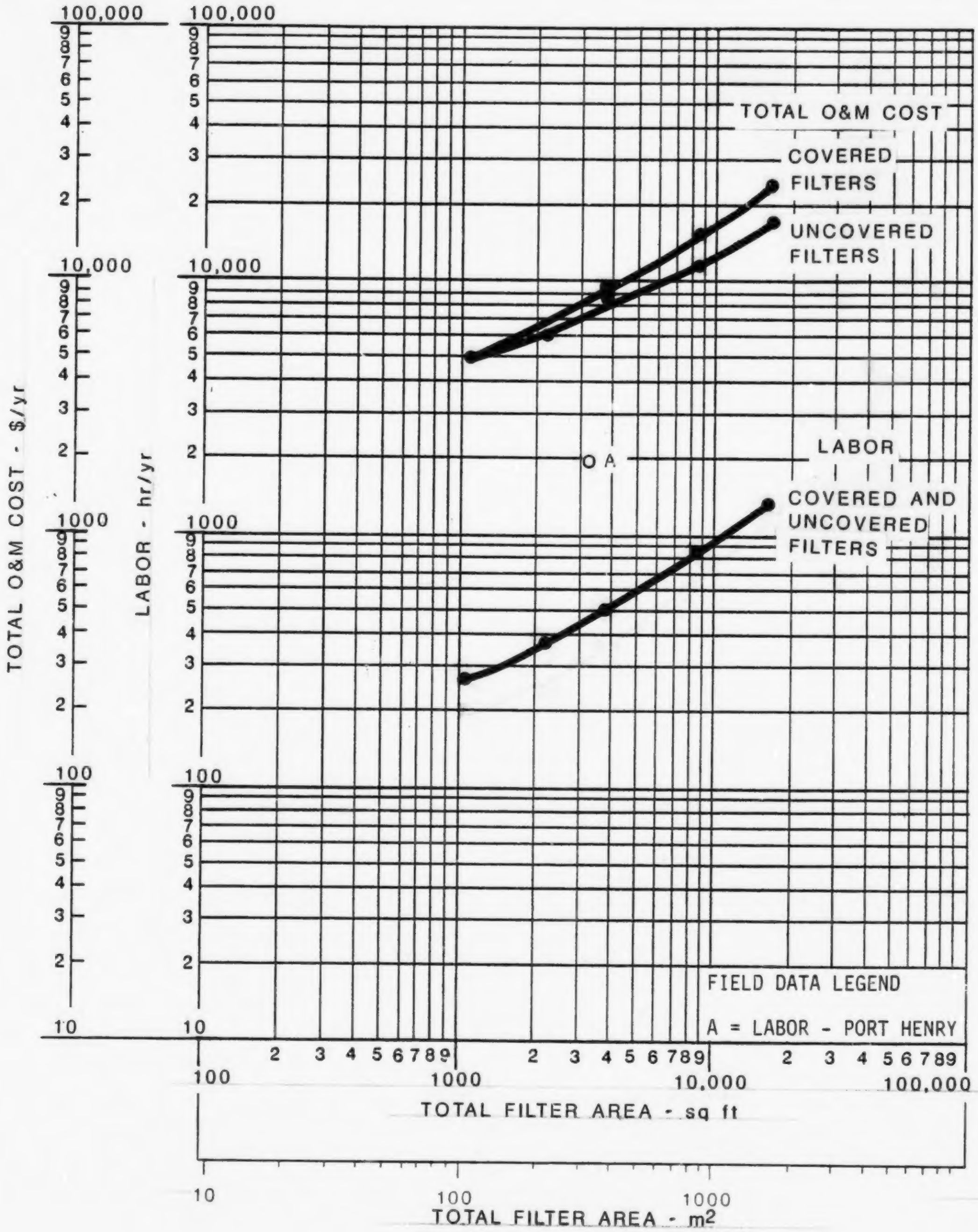


Figure 35. Operation and maintenance requirements for covered and uncovered slow sand filters - labor and total O&M cost.

REVERSE OSMOSIS

Introduction

Reverse osmosis utilizes semi-permeable membranes to remove a high percentage of almost all inorganic ions, turbidity, bacteria, and viruses. Most organic matter is also removed, with the exception of many halogenated and low-molecular-weight compounds.

There are differences between different membrane types in their ability to handle variations in pH, turbidity, and chlorine. The cellulose acetate membranes generally require the feedwater pH to be between 5 and 6 to minimize hydrolysis of the membrane. Polyamide type membranes are damaged by exposure to chlorine. The two most commonly used membrane configurations are hollow fine fiber and spiral wound. The spiral wound element has a higher tolerance for suspended solids and is less susceptible to fouling than the hollow fine fiber element.

The efficiency of the membrane elements in reverse osmosis systems may be impaired by scaling (because of slightly soluble or insoluble compounds) or by fouling (because of the deposition of colloidal or suspended materials). Because of the possibility of scaling and/or fouling, a very important consideration in the design of reverse osmosis systems is the provision of adequate pretreatment to protect the membrane from excessive scaling and fouling and to avoid frequent cleaning requirements. In the development of cost data for reverse osmosis, adequate pretreatment was assumed to precede the reverse osmosis process, but costs for pretreatment facilities such as chemical clarification and filtration are not included.

Brine disposal can also be a major cost consideration. Potential disposal methods include sewer discharge, evaporation ponds, ocean disposal and well injection. Brine disposal facilities and costs are not included in the reverse osmosis systems presented in this section. A separate section is included in this report for brine disposal.

Advances in membrane technology have led to the development of membranes which are capable of operating at low pressures, about 14.06 kg/cm^2 (200 psi), in contrast to high pressure membranes which operate at 28.12 kg/cm^2 (400 psi) or more. Advantageously, low pressure membranes result in a substantial savings in process electrical energy. There may be disadvantages to the use of low pressure membranes however. Disadvantages relative to high pressure membranes include lower percentage removal of many contaminants[1], lower allowable feed water TDS or lower percent water recovery, and membrane technology which is still developing.

In the following discussion, low pressure refers to systems operated at 14.06 kg/cm^2 (200 psi) and high pressure to systems operated at 28.12 kg/cm^2 (400 psi).

Impact of Raw Water Quality on Treatment Cost

Pretreatment Cost--

Pretreatment chemicals customarily utilized are sodium hexametaphosphate and sulfuric acid, with quantities required being highly variable, depending upon raw water quality. Another important parameter is silica, which may necessitate pretreatment for its removal. Costs for pretreatment chemicals and for silica pretreatment are not included in the following cost data.

Reverse osmosis units may be used for TDS removal, as well as the removal of individual contaminants addressed in the Interim Primary Drinking Water Regulations. The following paragraphs discuss the impact of raw water TDS, as well as individual contaminants in the raw water, upon treatment cost.

Total Dissolved Solids--

Feed water concentrations above 5,000 mg/L can lead to excessively high brine concentrations (>20,000 mg/L), which will generally result in a decrease in product water quality. To prevent this brine concentration buildup, it is necessary to lower the percentage of product water recovery. Lower product water recovery does not require a major change in the reverse osmosis unit, but does necessitate pumping larger quantities of feed water to the reverse osmosis unit. A revision in piping between the pressure vessels may also be required to change vessels to parallel operation, rather than operating some in series. This increases capital cost only slightly, due to the need for larger feed water pumps, but can create a large increase in electrical consumption and pretreatment chemicals, due to the larger quantity of water passed through the reverse osmosis units. A single pass unit will normally have a rejection of over 85% of feed water TDS. If a higher salt rejection is required, a high rejection membrane can be used, or the system can be operated at lower water recovery.

Individual Contaminants--

Little work has been conducted to determine the impact of varying feed concentrations of individual contaminants upon their percentage removal or the cost of removal. A recent publication by Huxstep[1] on work at Charlotte Harbor, Florida, indicated that arsenic (III), arsenic (V), fluoride, and nitrate percentage rejections were all independent of the feed concentrations. These contaminants were each added by spiking a natural groundwater of known concentration. High pressure membranes removed significantly higher percentages of these four components than did low pressure membranes.

Construction Costs

Construction cost data was developed for single stage (only one pass through the membrane) treatment systems which are capable of treating TDS concentrations up to about 2,000 mg/L for low pressure membranes and 10,000 mg/L for high pressure membranes. An operating pressure of 14.06 kg/cm^2 (200 psi) was utilized for low pressure membranes, and 28.12 kg/cm^2 (400 psi) for high pressure membranes. Construction costs are comparable for high and low pressure systems.

The temperature of the feedwater was assumed to be between 18.3° and 29.4°C (65° and 85°F), and the pH of the feedwater was assumed to be adjusted using acid injection to about 5.5 to 6.0 before the reverse osmosis process. The acid injection will prolong the life of a cellulose acetate membrane, but the primary function is to prevent calcium carbonate scale formation in the system. A degasifier following reverse osmosis will remove dissolved gases such as carbon dioxide and hydrogen sulfide from the product water, and will reduce neutralization requirements.

At TDS concentrations up to 5,000 mg/L, the assumed water recoveries for different flow ranges are as follows:

Feed Water Flow Range	Water Recovery (%)
2,500 - 10,000 gpd	40
10,000 - 50,000 gpd	50
50,000 - 100,000 gpd	65
100,000 gpd - 1.0 mgd	75

At concentrations above 5,000 mg/L, the percent recovery should be decreased in order to maintain a brine concentration less than 20,000 mg/L, which is necessary to limit osmotic pressure on the brine side of the membrane as well as to maintain quality of the product water. Salt rejections of over 85% should be achieved under these operating conditions. To maintain 20,000 mg/L in the brine, the following percent water recoveries are necessary:

TDS Concentration	Water Recovery (%)
5,000 mg/L	75
6,000 mg/L	70
7,000 mg/L	65
8,000 mg/L	60
9,000 mg/L	55
10,000 mg/L	50

It may be assumed that the capital cost of reverse osmosis treatment remains essentially unchanged as the TDS increases up to 10,000 mg/L, although the water recovery is decreased. This does increase the capacity (and therefore the capital cost) of the feedwater pumps, but this would increase the overall reverse osmosis system cost less than 5 percent. Thus, no separate cost data is presented for systems treating TDS concentrations greater than 5,000 mg/L. The largest effect is on O&M costs since the energy and pretreatment costs would increase in proportion to the increase in flow rate.

Commercial reverse osmosis systems are available from numerous manufacturers as either complete skid-mounted units or custom systems. For sizes ranging from 9.47 m^3/d (2,500 gpd) up to between 378.5-946.3 m^3/d (100,000-250,000 gpd), skid-mounted systems are generally used. Above 946.3 m^3/d (250,000 gpd), either skid-mounted or custom systems are used. An advantage of using multiple standard systems above 946.3 m^3/d (250,000 gpd), is the reliability provided by having several systems in case one unit needs to be shut down for repairs. This cost analysis used skid-mounted units, or multiples of such units, for all size ranges.

Components taken into account in the construction cost estimates include housing, structural steel and miscellaneous metalwork, tanks, piping, valves, high pressure feed water pumps, reverse osmosis membrane elements and pressure vessels, flowmeters, cartridge filters, acid and polyphosphate feed equipment, cleaning equipment, caustic feed equipment, and a degasifier. The cost data are based on the use of either spiral-wound or hollow fine-fiber reverse osmosis membranes. Membrane materials can be cellulose acetate, polyamide, or thin film composite. A layout of a typical small system reverse osmosis system is shown in Figure 36.

Brine disposal costs and product water pumping costs are not included in the estimates. Construction cost estimates are presented in Table 46 and also in Figure 37.

Operation and Maintenance Requirements and Costs

Process electrical energy is required for the feed water pumps, pre- and post-treatment chemical feed pumps, and the degasifier. The combined feed water pump/motor efficiency increases as flow increases. The feed water pump/motor efficiencies which were used in the calculations were: 40% up to 37.85 m^3/d (10,000 gpd) plant capacity, 50% up to 378.5 m^3/d (100,000 gpd) plant capacity, and 60% over 378.5 m^3/d (100,000 gpd) plant capacity. Energy requirements used for the chemical feed pumps and degasifier were 10% of the high pressure pump energy for plant capacities less than 189.3 m^3/d (50,000 gpd), and 5% for plant capacities over 189.3 m^3/d (50,000 gpd).

Process energy varies with the percent water recovery. As discussed under Construction Costs, higher percent water recoveries are typically used as system size increases, resulting in lower process energy requirements per unit of water produced. However, as TDS increases above 5,000 mg/L, lower percent water recoveries are necessary to maintain a reasonable brine concentration and to prevent deterioration of product water quality. Process electrical data has been developed for feed water TDS concentrations of 2,000 mg/L for low pressure systems and 5,000, 8,000, and 10,000 mg/L for high pressure systems.

Electrical energy for building lighting, heating, and ventilating was calculated based on an estimated floor area required for complete housing of the reverse osmosis equipment, with the exception of the degasifier, which is located outside. A building energy requirement of 209.8 $kwh/m^2/y$ (19.5 kwh/sq ft/yr) was used for lighting, heating, and ventilation. This requirement is based upon a lighting use factor of three hours per day.

The largest maintenance material requirement is for membrane replacement; a membrane life of three years was used in the cost estimates. Other maintenance material requirements are for replacement of cartridge filters, for membrane cleaning chemicals, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. Costs for pretreatment chemicals, such as acid and polyphosphate, and post-treatment chemicals, such as caustic, are not included in the maintenance material estimates, but they

TABLE 46. CONSTRUCTION COST SUMMARY FOR REVERSE OSMOSIS SYSTEMS

Cost Category	Plant Capacity, gpd					
	2,500	10,000	50,000	100,000	500,000	1,000,000
Manufactured Equipment	$20,300	$30,000	$ 69,600	$123,000	$454,800	$ 877,400
Labor	800	1,200	1,500	2,800	7,500	14,600
Electrical, Instrumentation	3,200	4,600	10,700	18,700	45,900	62,100
Housing	11,900	13,900	16,400	18,500	38,400	52,500
Subtotal	36,200	49,700	98,200	163,000	546,600	1,006,600
Design Contingencies	5,400	7,500	14,700	24,500	82,000	151,000
Total	$41,600	$57,200	$112,900	$187,500	$628,600	$1,157,600

Notes:
1. Housing requirements from smallest plant capacity to largest are 140, 170, 210, 250, 800, and 1,500 sq ft. Ceiling height in buildings is 14 ft.
2. Costs are valid for feed water TDS concentrations up to 10,000 mg/L. However, percentage recovery of feed water decreases above 5,000 mg/L TDS.

are discussed in the following section. Maintenance material costs increase slightly as the percent recovery drops, due to increased pumping to the reverse osmosis unit.

Labor requirements are for cleaning and replacing membranes, replacing cartridge filters, maintaining the high pressure and other pumps, preparing treatment chemicals and determining proper dosages, maintaining chemical feed equipment, and monitoring performance of the reverse osmosis membranes. Membrane cleaning was assumed to occur monthly. In estimating labor requirements, a minimum of about one hr/day of labor was assumed for the smallest plant.

Operation and maintenance requirements are summarized in Table 47 for low pressure systems and in Table 48 for high pressure systems, and are illustrated for both high and low pressure systems in Figures 38 and 39.

TABLE 47. OPERATION AND MAINTENANCE SUMMARY FOR LOW PRESSURE REVERSE OSMOSIS SYSTEMS

Average Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
2,500	2,800	9,900	12,700	500	340	5,100
10,000	3,300	26,300	29,600	1,700	360	7,800
50,000	4,100	100,100	104,200	8,000	480	20,600
100,000	4,900	180,400	185,300	14,600	610	34,300
500,000	15,600	853,200	868,800	67,100	870	137,500
1,000,000	29,300	1,606,000	1,635,300	117,900	1,130	244,800

Note: Total cost is based on $0/07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

The principal chemicals required in small reverse osmosis systems are sodium hexametaphosphate for control of scaling and fouling, sulfuric acid for pH adjustment prior to treatment, and sodium hydroxide to increase the pH following treatment. The required cost for each chemical is a function of the dosage, the unit cost of the chemical and the percent water recovery. Using the percentage of water recovery discussed previously in the text, and the following dosages and unit chemical costs, the annual chemical costs in Table 49 were calculated.

Chemical	Dosage	Unit Cost
Sodium Hexametaphosphate	6 mg/L	$1.10/lb
Sulfuric Acid	75 mg/L	$0.08/lb
Sodium Hydroxide	15 mg/L	$0.17/lb

TABLE 48. OPERATION AND MAINTENANCE SUMMARY FOR REVERSE OSMOSIS SYSTEMS

Average Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Processs	Total			
Feed Water TDS Concentrations Up to 5,000 mg/L						
2,500	2,800	18,000	20,800	500	340	5,700
10,000	3,300	48,200	51,500	1,700	360	9,300
50,000	4,100	191,100	195,200	8,000	480	27,000
100,000	4,900	344,400	349,300	14,600	610	45,800
500,000	15,600	1,629,000	1,644,600	67,100	870	191,800
1,000,000	29,300	3,066,000	3,095,300	117,900	1,130	347,000
Feed Water TDS Concentrations = 8,000 mg/L						
2,500	2,800	18,000	20,800	500	340	5,700
10,000	3,300	48,200	51,500	1,700	360	9,300
50,000	4,100	191,100	195,200	8,000	480	27,000
100,000	4,900	373,000	377,900	14,900	630	48,300
500,000	15,600	2,036,200	2,051,800	70,200	940	224,200
1,000,000	29,300	3,832,500	3,861,800	122,900	1,220	406,700
Feed Water TDS Concentrations = 10,000 mg/L						
2,500	2,800	18,000	20,800	500	340	5,700
10,000	3,300	48,200	51,500	1,700	360	9,300
50,000	4,100	191,100	195,200	8,000	480	27,000
100,000	4,900	447,700	452,600	15,500	680	54,700
500,000	15,600	2,443,500	2,459,100	73,200	1,020	256,600
1,100,000	29,300	4,599,000	4,628,300	127,700	1,310	466,100

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 49. TYPICAL CHEMICAL COSTS FOR REVERSE OSMOSIS SYSTEMS

Average Plant Flow Rate, gpd	Sodium Hexametaphosphate, $/yr	Sulfuric Acid, $/yr	Sodium Hydroxide, $/yr	Total Chemical Cost, $/yr
Feed Water TDS Concentrations Up to 5,000 mg/L				
2,500	130	120	50	300
10,000	500	460	200	1,160
50,000	2,000	1,830	780	4,610
100,000	3,100	2,800	1,200	7,100
500,000	13,400	12,200	5,200	30,800
1,000,000	26,800	24,300	10,300	61,400
Feed Water TDS Concentrations = 8,000 mg/L				
2,500	130	120	50	300
10,000	500	460	200	1,160
50,000	2,000	1,830	780	4,610
100,000	3,400	3,000	1,300	7,700
500,000	16,800	15,200	6,500	38,500
1,000,000	33,500	30,400	12,900	76,800
Feed Water Concentrations = 10,000 mg/L				
2,500	130	120	50	300
10,000	500	460	200	1,160
50,000	2,000	1,830	780	4,610
100,000	4,000	3,700	1,600	9,300
500,000	20,100	18,300	7,800	46,200
1,000,000	40,200	36,500	15,500	92,200

Note: Chemical dosages and costs used in this table were:
Sodium Hexametaphosphate - 6 mg/L; $1.10/lb
Sulfuric Acid - 75 mg/L; $0.08/lb
Sodium Hydroxide - 15 mg/L; $0.17/lb

The required chemical dosages will vary widely between water supplies, and laboratory or pilot plant testing should be used to determine requirements. Additionally, the cost of chemicals will be a function of the geographical area and the quantity of chemical purchased.

Field Data Collection

Operating data on reverse osmosis treatment systems were collected at the Charlotte Harbor Water Association, Harbor Heights, Florida, and the Bryn Mawr Water Company, Vero Beach, Florida. The Charlotte Harbor plant has two treatment modules which operate at 27.4 kg/cm^2 (390 psi) and have a combined treatment capacity of 1,136 m^3/d (0.3 mgd) and one low pressure unit which operates at 16.5 kg/cm^2 (235 psi) and has a treatment capacity of 568 m^3/d (0.15 mgd). The total operating flow rate of both the high and low pressure units is 1,120 m^3/d (0.296 mgd). The TDS concentration in the raw water supply was not obtained during the field sampling.

The Bryn Mawr plant at Vero Beach has an installed capacity of 454 m^3/d (0.12 mgd) and an operating flow rate of 163 m^3/d (0.043 mgd). The operating pressure is 28.1 kg/cm^2 (400 psi). The TDS in the raw water supply was not noted during collection of field data.

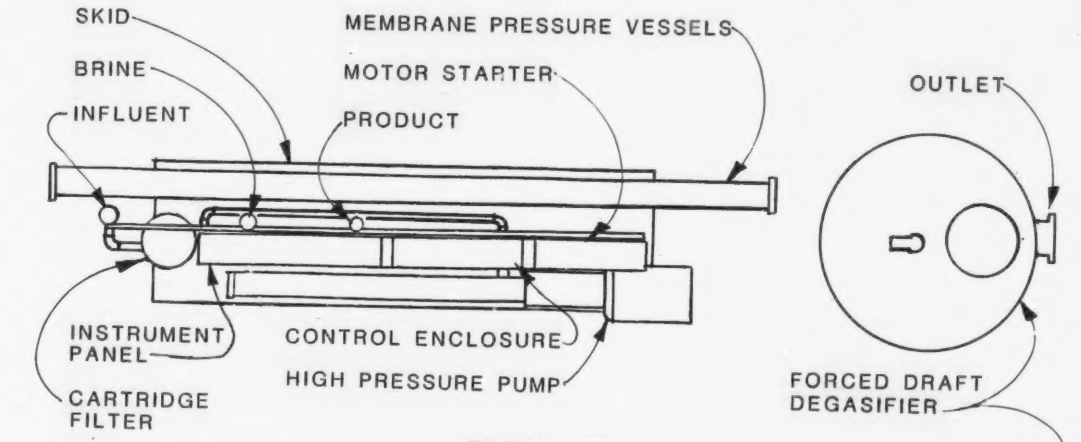
A comparison of field operating data and information from Figures 38 and 39 is shown following:

	Charlotte Harbor		Vero Beach	
	Field Data	Data From Figures 38 and 39	Field Data	Data From Figures 38 and 39
Electrical Energy, kwh/hr				
Process	-	750,000	-	160,000
Building	-	14,000	-	4,000
Total	788,200	764,000	218,800	164,000
Maintenance Material, $/yr	10,400	38,000	890	6,000
Labor, hr/yr	5,140	800	640	480

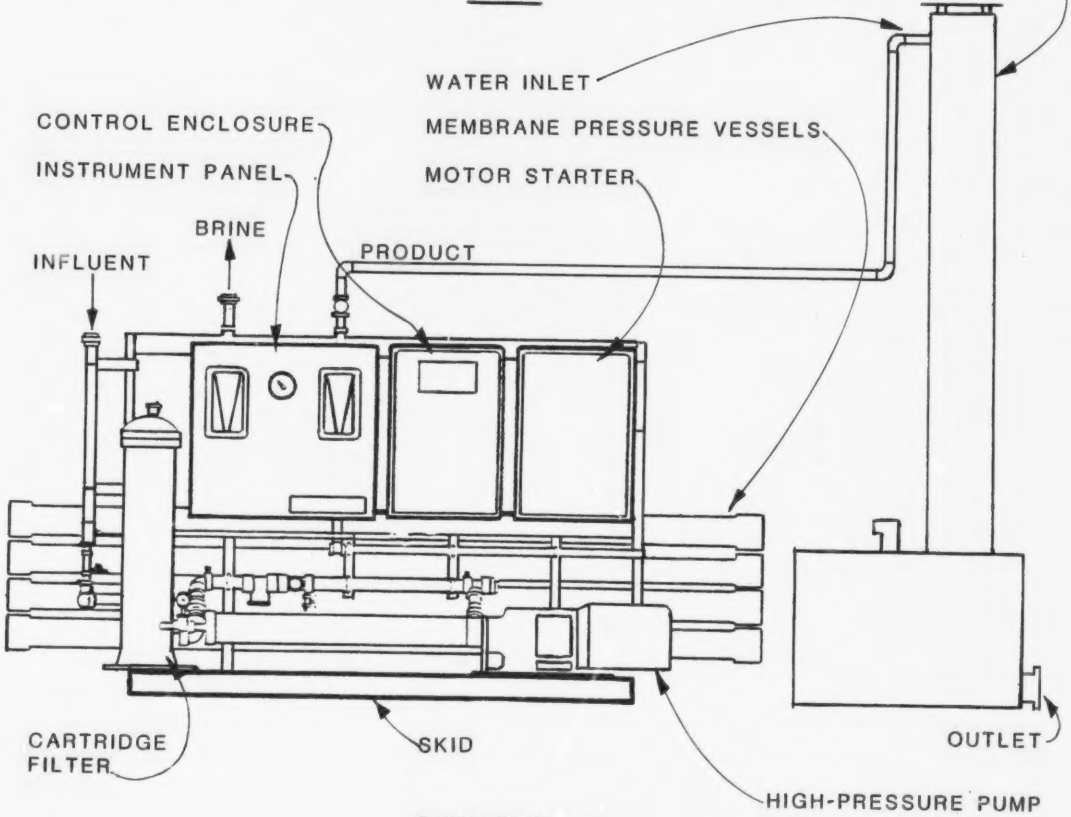
Maintenance material requirements are low at both plants because replacement of membranes has not been necessary at either plant. However, Figure 38 data include a cost for membrane replacement every three years. The large difference in labor requirement at Charlotte Harbor is believed to be the result of an inappropriate division of labor between the treatment plant and the water distribution system.

References

1. Huxstep, M.R., "Inorganic Contaminant Removal From Drinking Water By Reverse Osmosis," EPA Report 600/52-81-115, October, 1981.


SKID
BRINE
INFLUENT
MEMBRANE PRESSURE VESSELS
MOTOR STARTER
PRODUCT
OUTLET
INSTRUMENT PANEL
CONTROL ENCLOSURE
HIGH PRESSURE PUMP
CARTRIDGE FILTER
FORCED DRAFT DEGASIFIER

PLAN


WATER INLET
CONTROL ENCLOSURE
MEMBRANE PRESSURE VESSELS
INSTRUMENT PANEL
MOTOR STARTER
BRINE
INFLUENT
PRODUCT
CARTRIDGE FILTER
SKID
OUTLET
HIGH-PRESSURE PUMP

ELEVATION

Figure 36. Typical-skid mounted reverse osmosis installation

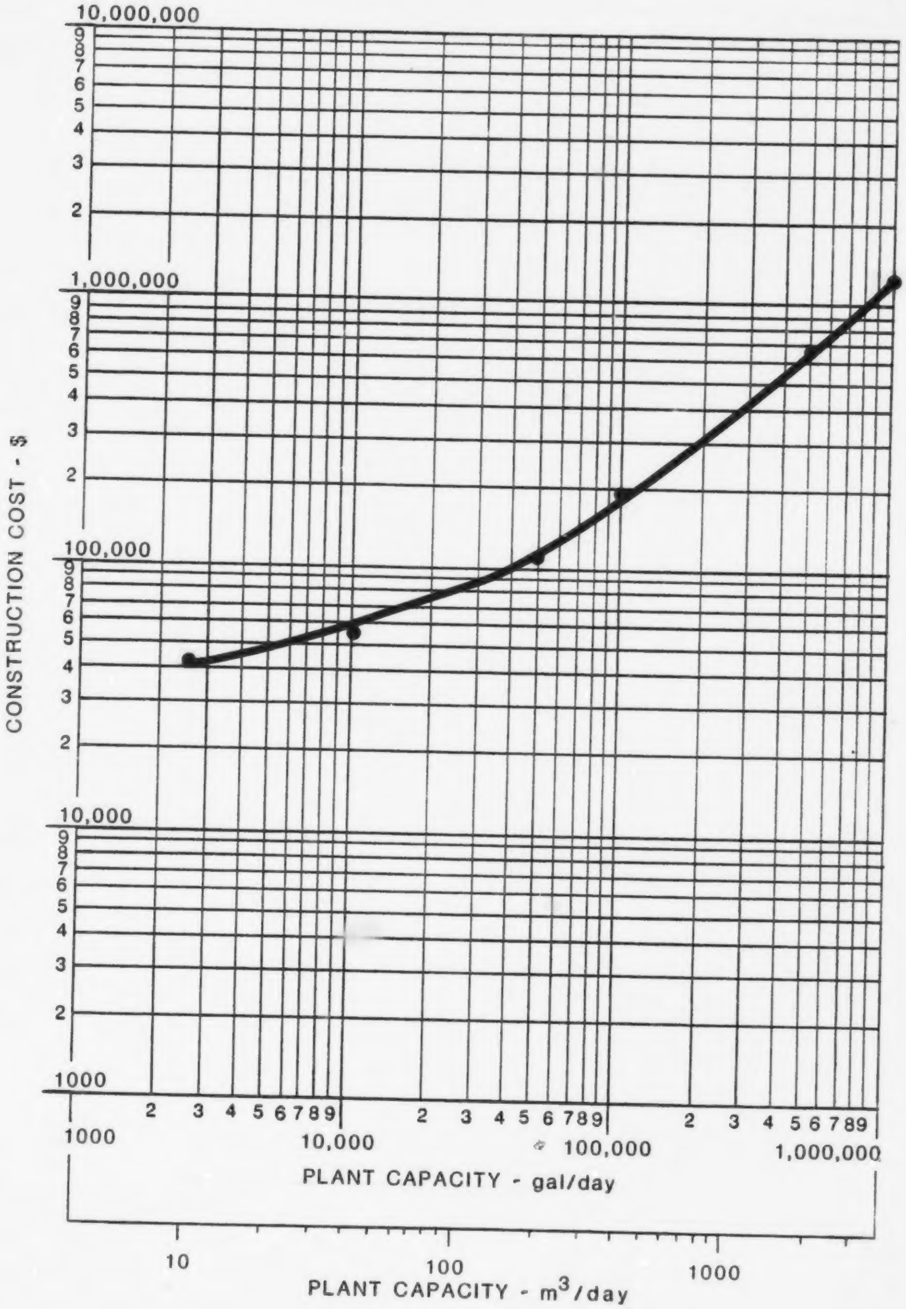


Figure 37. Construction cost for reverse osmosis systems.

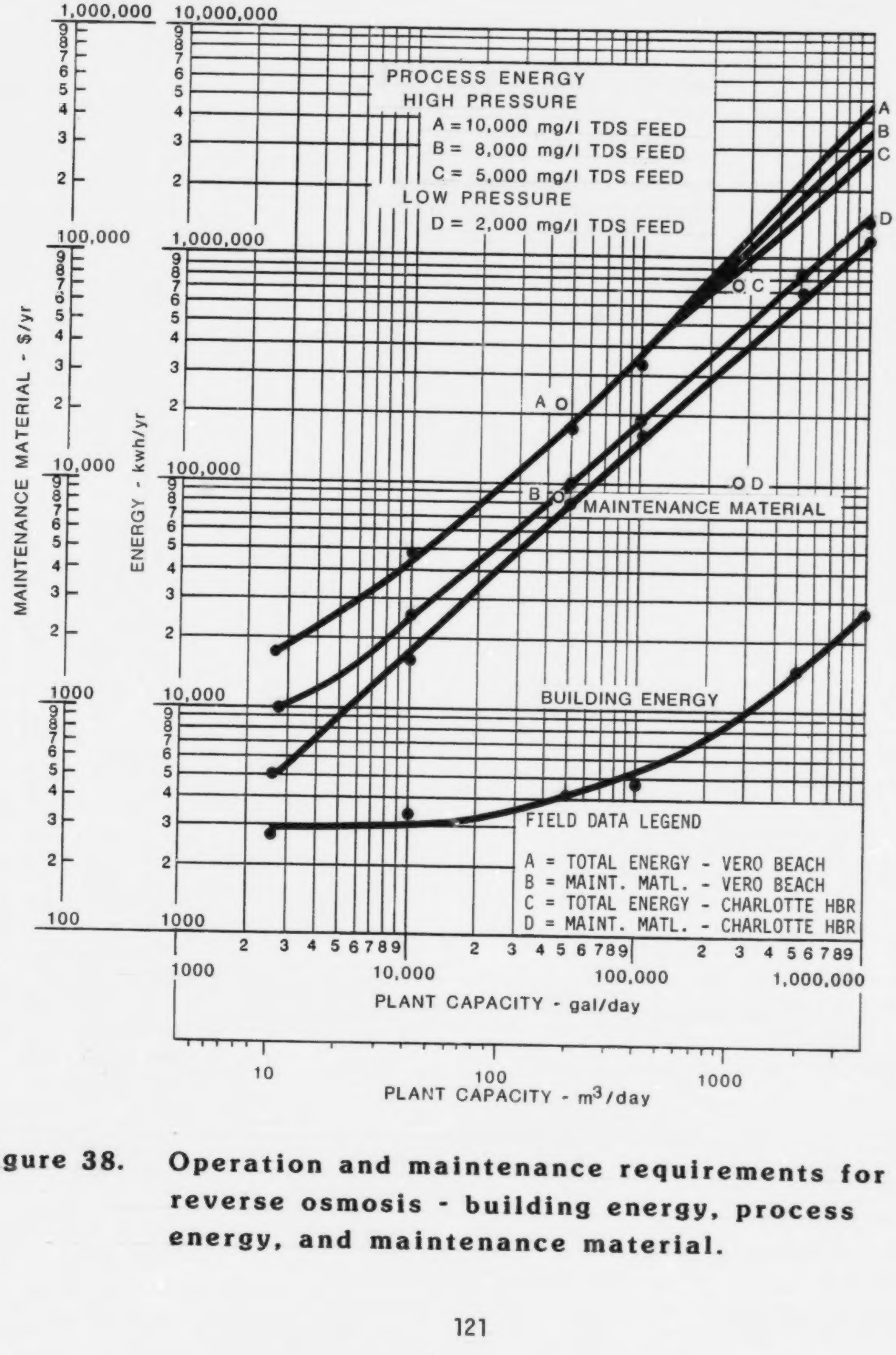


Figure 38. **Operation and maintenance requirements for reverse osmosis - building energy, process energy, and maintenance material.**

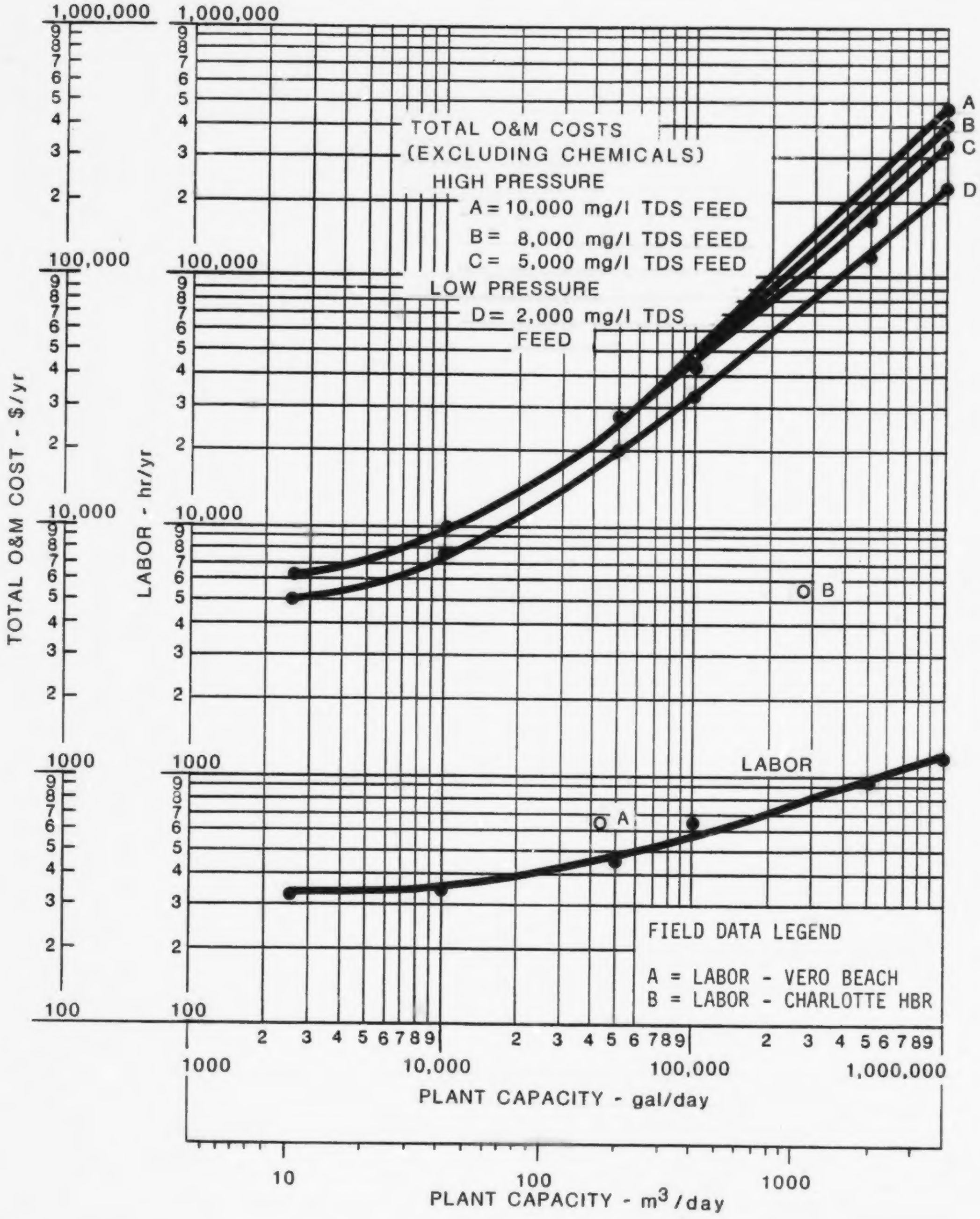


Figure 39. **Operation and maintenance requirements for reverse osmosis systems - labor and total O&M cost.**

ELECTRODIALYSIS

Introduction

Electrodialysis (ED) is a process with a history of over 25 years operation on brackish well water supplies. A 2,460 m^3/d (650,000 gpd) ED plant began operation on well water at Buckeye, Arizona, in September 1962 and has been in continuous operation to date. ED plants are also in operation desalting municipal water supplies at Sanibel Island, Florida, and at the Foss Reservoir in Oklahoma. The process is also widely used for desalting industrial process water.

In the ED process, brackish water flows between alternating cation permeable and anion permeable membranes. A direct electric current (DC) provides the motive force to cause ions to migrate through the membranes. Many alternating cation and anion membranes, each separated by a plastic spacer, are assembled into membrane stacks. The spacers contain the water streams within the stack and direct the flow of water through a circuitous path across the exposed face of the membranes. Several hundred membranes and their separating spacers are usually assembled between a single set of electrodes to form a membrane stack. Back-up end plates held by tie-rods hold the membranes and spacers in place.

Passage of water between the membranes of a single stack, or stage, usually requires 10 to 20 seconds, during which the entering minerals in the feed water are removed. The actual percentage removal that is achieved varies with water temperature, type and amounts of ions present, flow rate of the water, current density and the number of membranes in each stage. Typical removals per stage range from 30 to 55%, and systems employ two to six stages. The process is effective for the removal of organics, mostly in the form of short chain organics, although the mechanism of removal is not fully understood at this time. Short chain organics removals of 30-40% have been demonstrated. An ED system will operate at temperatures up to 45°C (115°F) and the removal efficiency increases with increasing temperature. Electrodialysis membranes are commonly guaranteed for as long as 5 years and experience has demonstrated an effective life of over 10 years.

Ionics, Inc. developed a type of ED unit which does not require the addition of acid or other chemicals for scale control during normal operation. This system reverses the DC current direction and the flow path of the dilution and concentrating streams every 15 to 30 minutes, thus it is called electrodialysis reversal (EDR). The electrodes reverse by switching the polarity of the cathodes and anodes. The stream flow paths also exchange their source every 15 minutes. Motor operated valves controlled by timers switch the streams so that the flow path that was previously the diluting stream becomes the concentrating stream and the flow path that was previously the concentrating stream becomes the diluting stream. Virtually all ED plants constructed since 1975 are the reversal (EDR) type. Over 700 EDR plants have been installed worldwide, for domestic water treatment and other applications, with capacities ranging between 3.7 and 22,730 m^3/d (1,000 gpd and 6 mgd).

Impact of Raw Water Quality on Treatment Cost

Water quality parameters which affect treatment cost include water temperature, pH, and the type and quantity of ions present in the supply. As water temperature increases, the treatment process becomes more effective, up to the maximum recommended operating temperature of 45°C (115°F). As the feedwater TDS concentration increases, process energy requirements increase, in direct proportion to the TDS concentration increase. As a general rule, energy consumption is 0.52 to 0.66 kwh/m^3 of product water/1,000 mg/L of salt removed (2.0 to 2.5 kwh/1,000 gal/1,000 mg/L). The actual value will be a function of temperature and specific ions in the feedwater stream. The percentage removal of a particular constituent depends upon characteristics of the particular ion. For example, nitrate ion is removed at a more rapid rate than the bicarbonate ion. Determination of the percentage removal of a particular constituent is complex and information on removals is best obtained from equipment manufacturers.

Pretreatment of raw water may be required to prevent membrane fouling. Generally, pretreatment is not required on a well supply. Pretreatment is normally recommended when treating surface water supplies, waters with more than 0.1 mg/L of manganese, 0.3 mg/L of iron, 0.3 mg/L of hydrogen sulfide, or 0.3-0.5 mg/L of free chlorine. Polyphosphates and polymeric substances generally do not cause fouling. Turbidity levels over 3 NTUs generally require multi-media filtration, to prevent frequent replacement of the disposable cartridge filters which are used as final filters. Necessity for pretreatment will increase overall treatment cost.

Construction Costs

Construction costs for electrodialysis reversal (EDR) type plants are presented in Table 50 and in Figure 41, and a typical process layout is shown in Figure 40. The plants are capable of about 50-99 percent salt removal at water recoveries (ratio of product water to feed water) of 60 to 95 percent with feed water temperatures of 4.4° to 46°C (40° to 115°F). The actual performance of an ED plant is dependent on feed water characteristics, plant configuration and mode of plant operation. The construction costs are typical for plants treating water with TDS concentrations up to 5,000 mg/L. The manufactured equipment includes skid mounted EDR units with cartridge filters, feed and brine pumps, system valves and piping, electrical control panel and rectifier.

A building is required to enclose the equipment and protect it from the weather. In addition to providing the space required for the equipment, there should be areas provided for maintenance and storage. Access to the equipment area should include an overhead door at least 2.44 m (8 ft) in width and height.

The floor in the equipment area should be plain finished concrete, adequate for a maximum loading of 3,660 kg/m^2 (750 lb/sq ft). Drains are necessary and the floor should be pitched for drainage to provide a clean and dry equipment area.

TABLE 50. CONSTRUCTION COST SUMMARY FOR ELECTRODIALYSIS

Cost Category	Plant Capacity, gpd					
	1,500	8,000	30,000	100,000	300,000	1,000,000
Excavation and Sitework	$ 2,100	$ 3,000	$ 3,500	$ 4,700	$ 5,000	$ 9,300
Manufactured Equipment	15,500	36,100	82,400	128,800	278,100	978,500
Concrete	300	500	900	1,300	2,300	4,500
Labor, Installation	700	1,500	1,700	2,600	5,800	20,300
Electrical, Instrumentation	2,400	4,300	8,200	10,300	19,400	58,500
Housing	7,800	10,800	18,000	22,500	32,100	42,000
Subtotal	28,800	56,200	114,700	170,200	342,700	1,113,100
Design Contingencies	4,300	8,400	17,200	25,500	51,400	167,000
Total	$33,100	$64,600	$131,900	$195,700	$394,100	$1,280,100

Note: Housing requirements from smallest plant capacity to largest are 100, 150, 300, 410, 765, and 2,500 sq ft, respectively. All housing has a 14 ft height.

The equipment skids must be leveled and should be anchored to the floor. Interconnections between the skid and stacks are all prefabricatd and included as part of the equipment package. Hydraulic interconnections are made with bolted flanges and the electrical interconnections are cables between pre-wired terminal connections. There is one connection for each of the following: feed water, product water, waste brine and electrical power.

Brine disposal costs and product water pumping costs are not included.

Operation and Maintenance Requirements and Costs

Operation and maintenance data are summarized in Table 51, and are also shown in Figures 42 and 43. Electrodialysis plants in these estimates are designed to operate automatically but can be switched to manual operation at the control panel. Starting and stopping of the ED unit is normally from an electrical signal initiated from the treated water storage tank level controller. If the feed water pressure or concentrate pressure is too high or low within the plant, the unit will shut down automatically. This shut down can be wired to either an alarm or signal light, as required, at the most appropriate location.

The product water is continuously monitored by a conductivity controller which is pre-set for a particular quality. If the specified product water quality is not being obtained, the water is automatically diverted to waste and an alarm is activated. An operator should monitor the control panel daily and record the pressures, flow rates, electrical conditions, and other parameters, to establish the long term operating conditions. Data observation and adjustments to the plant will average approximately 0.5 hour per day.

The primary maintenance requirement is for membrane cleaning and replacement. The labor and material allowances include periodic membrane cleaning (chemical costs are not included), membrane replacement, cartridge filter replacement and other equipment maintenance. Electricity requirements are estimated to be 0.0503 kwh per 100 mg/L TDS removed per m^3 (0.2 kwh per 100 mg/L TDS removed per 1,000 gal) produced plus 0.793 kwh per m^3 (3.0 kwh per 1,000 gal) for pumping feed water. These requirements are expressed per unit volume of product water.

Typical Chemical Requirements and Costs

For most waters, continuous addition of chemicals to prevent fouling is not necessary. In certain cases, however, small quantities of acid may be added to the brine/waste stream to control calcium carbonate, keeping it at a Langelier Index of +2.2. Thus, the EDR process can handle scaling calcium carbonate levels, except in extreme cases, where acid must be added. If the calcium sulfate concentration in the brine stream exceeds 150% of saturation, sodium hexametaphosphate or another polyphosphate sequestering agent must be used. With sequestering agents, calcium sulfate concentrations exceeding 440% can be handled.

Periodic chemical cleaning of the stacks is necessary on a bi-weekly to monthly basis, in order to remove calcium or iron deposits, and in certain cases organic or colloidal deposits. Calcium deposits are removed using 3-5%

TABLE 51. OPERATION AND MAINTENANCE SUMMARY FOR ELECTRODIALYSIS

Average Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
TDS Concentration = 1,000 mg/L						
1,500	2,000	2,600	4,600	200	270	3,500
8,000	2,900	14,000	16,900	800	370	6,100
30,000	5,900	52,600	58,500	2,800	460	12,000
100,000	8,000	175,200	183,200	9,200	550	28,100
300,000	14,900	525,600	540,500	23,000	640	67,900
1,000,000	48,900	1,752,000	1,800,900	91,300	1,100	229,500
TDS Concentration = 2,000 mg/L						
1,500	2,000	3,700	5,700	200	300	3,900
8,000	2,900	19,900	22,800	900	410	7,000
30,000	5,900	74,500	80,400	3,300	510	14,500
100,000	8,000	248,200	256,200	11,000	610	35,700
300,000	14,900	744,600	759,500	27,400	700	88,300
1,000,000	48,900	2,482,000	2,530,900	109,500	1,200	299,900
TDS Concentration = 3,000 mg/L						
1,500	2,000	4,800	6,800	200	330	4,300
8,000	2,900	25,700	28,600	1,100	450	8,100
30,000	5,900	96,400	102,300	3,900	560	17,200
100,000	8,000	321,200	329,200	12,800	670	43,200
300,000	14,900	963,600	978,500	32,000	770	109,000
1,000,000	48,900	3,212,000	3,260,900	127,800	1,320	370,600

Notes: 1. Process energy is based upon TDS reduction to 100 mg/L.
2. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

solution of hydrochloric acid, and organic or colloidal deposits are removed by feeding a pH 11 brine. Bacterial deposits that might grow on the membranes from a long period of non-use can be removed by shock treatment with 20-50 ppm of sodium hypochlorite (bleach). This free chlorine cleaning, and the bacteria itself will not harm the EDR membranes.

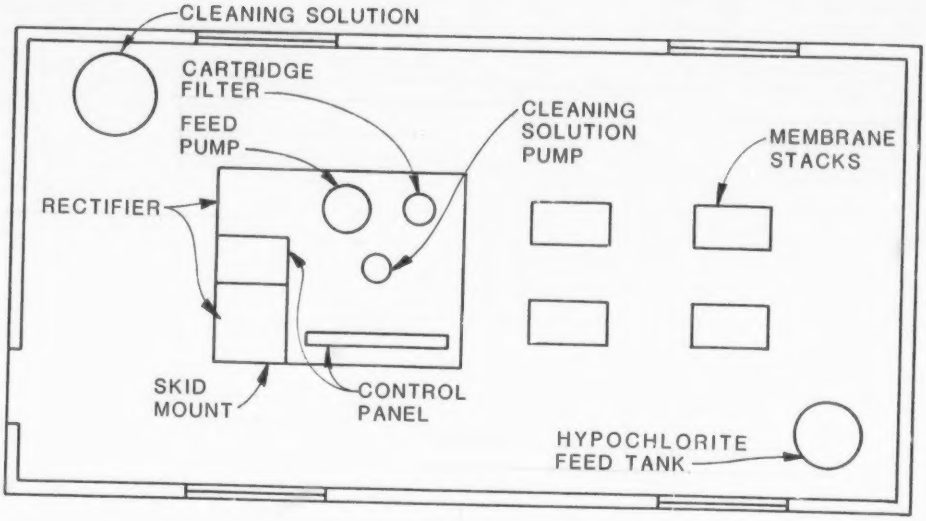
Cleaning, which is done in-place, does not require stack dissembly. Typical times required for in-place cleaning are 1/2 hour for the chemical cleaning and 1/2 hour for raw water flush of the stacks. Assuming both an acid and salt/caustic flush of the membranes, chemical costs are approximately 0.26¢/m^3 (1¢/1,000 gal) produced.

Field Data Collection

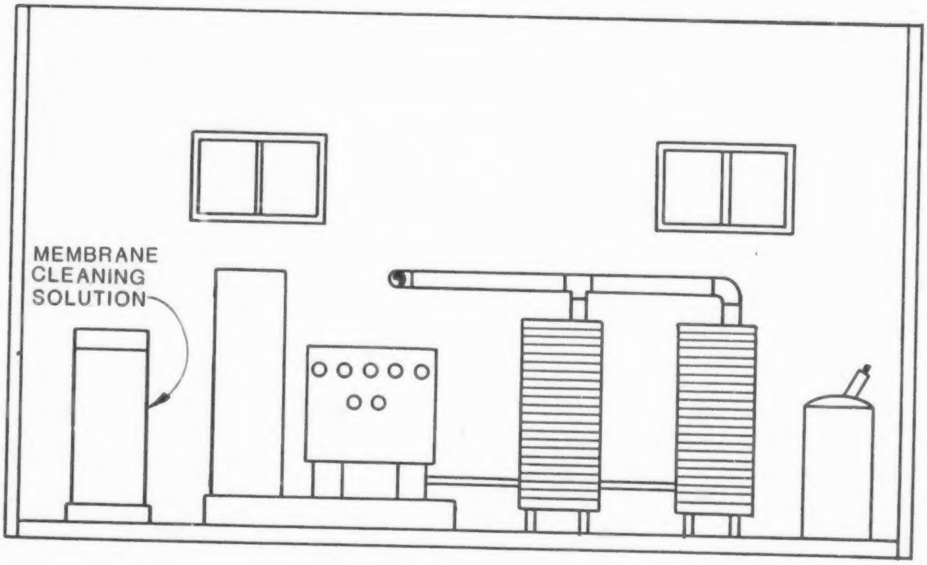
Field operating data were collected at Dell City, Texas. This plant has a design capacity of 378.5 m^3/d (0.1 mgd) and an operating flow rate of 285.4 m^3/d (0.0754 mgd). Feed water TDS was approximately 3,000 mg/L. A comparison of field data and data from Figures 42 and 43 is shown following:

	Field Data	Data From Figures 42 and 43
Electrical Energy, kwh/hr		
Process	-	260,000
Building	-	8,500
Total	317,180	268,500
Maintenance Material, $/yr	13,435	8,000
Labor, hr/yr	1,245	650

All requirements from Figures 42 and 43 are lower than the field data. Labor requirements at Dell City may be high, as they were determined by estimating the treatment plant labor requirements as 15% of the total City payroll. Field data electrical requirements include pumping to the distribution system, which is why they are higher than Figure 42.


CLEANING SOLUTION
CARTRIDGE FILTER
FEED PUMP
CLEANING SOLUTION PUMP
MEMBRANE STACKS
RECTIFIER
SKID MOUNT
CONTROL PANEL
HYPOCHLORITE FEED TANK

PLAN VIEW


MEMBRANE CLEANING SOLUTION

ELEVATION VIEW

Figure 40. **Typical electrodialysis installation.**

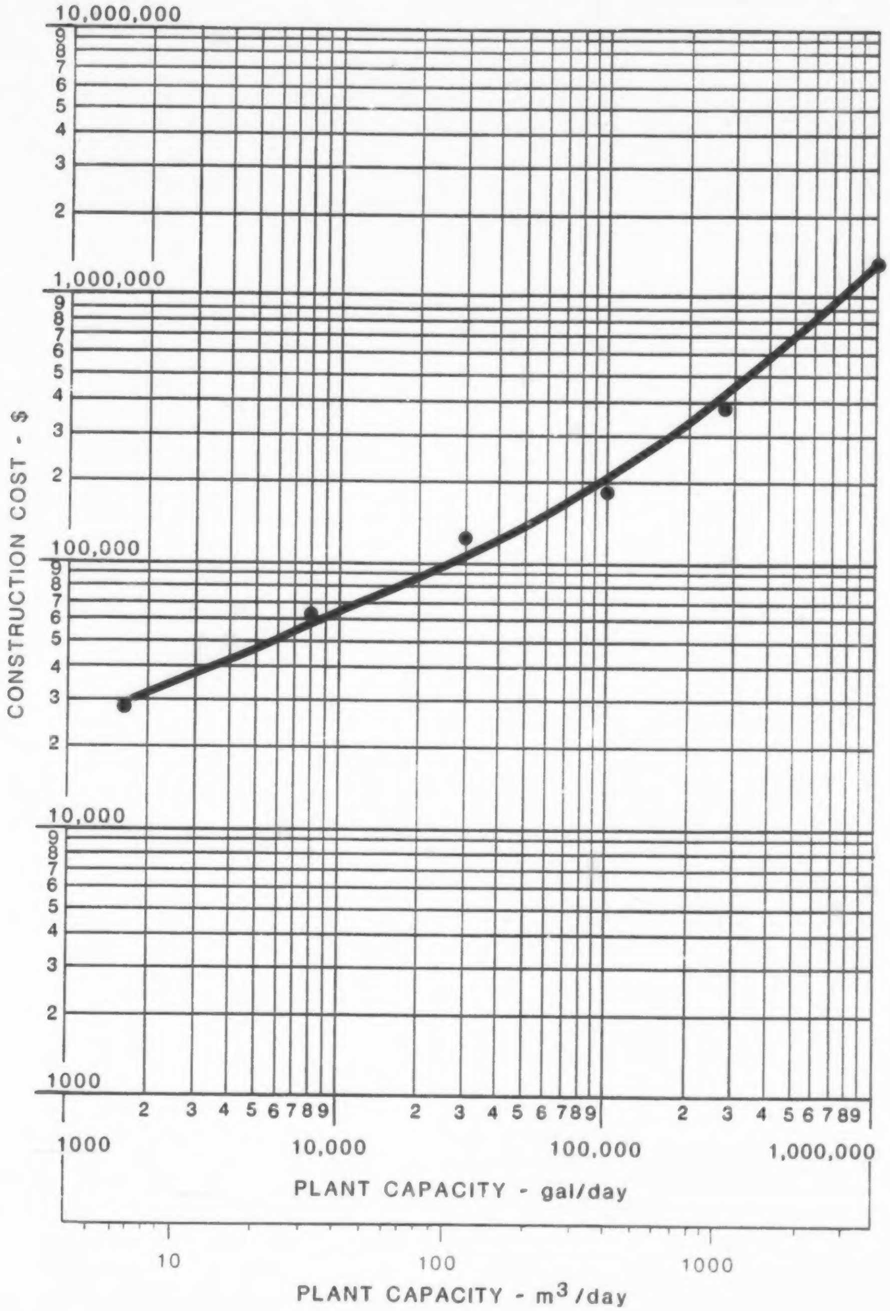


Figure 41. Construction cost for electrodialysis.

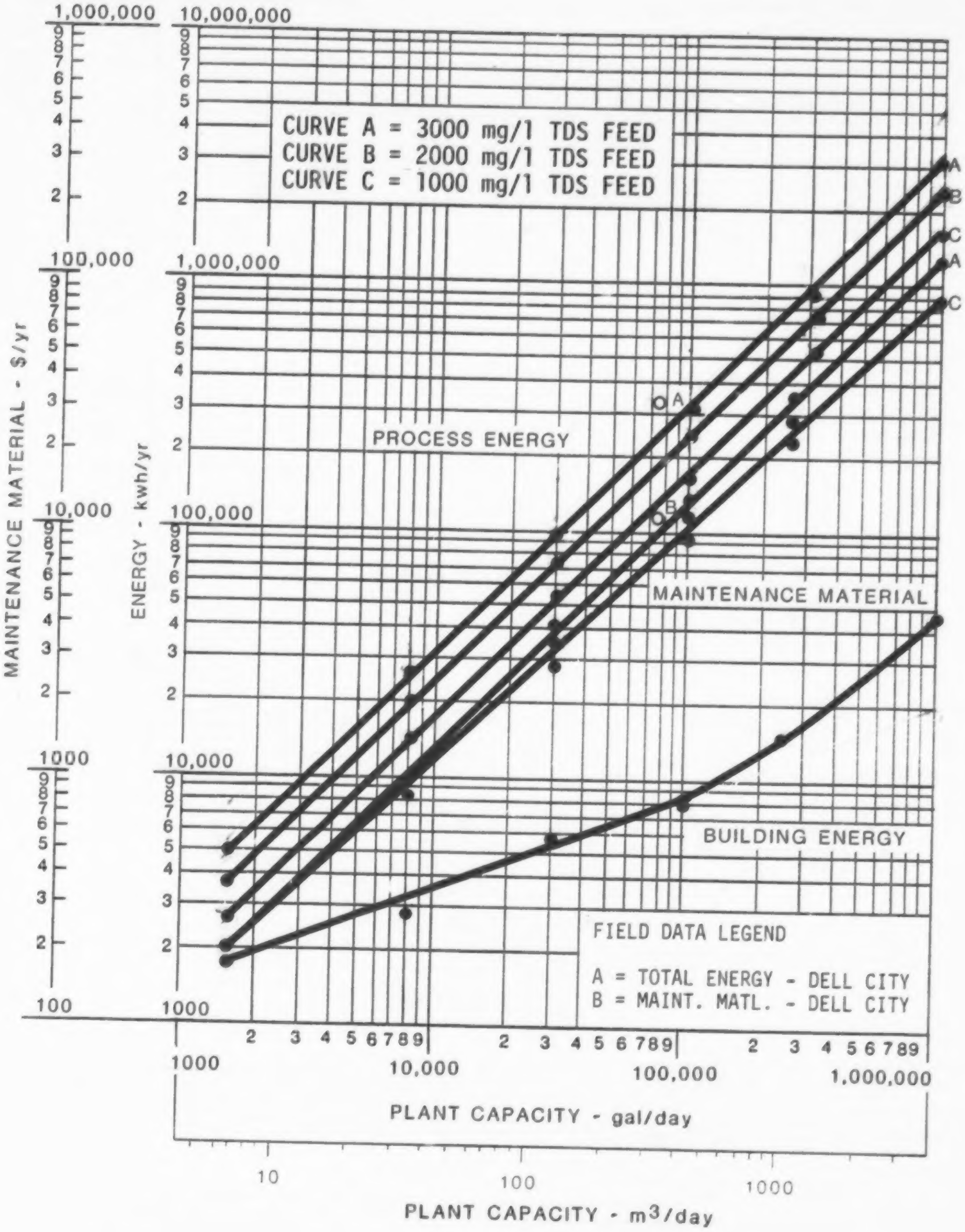


Figure 42. Operation and maintenance requirements for electrodialysis - building energy, process energy, and maintenance material.

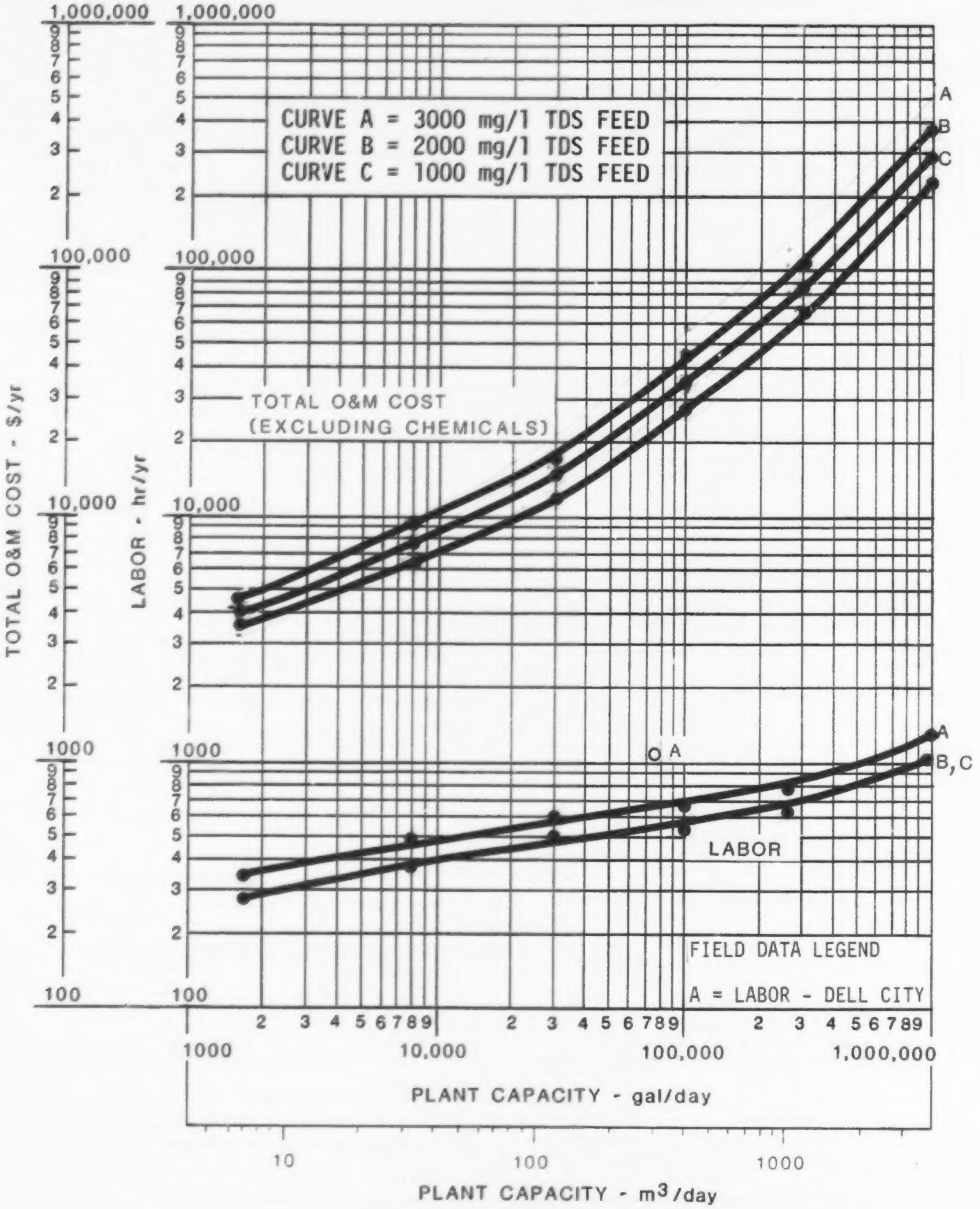


Figure 43. Operation and maintenance requirements for electrodialysis - labor and total O&M cost.

PACKAGE ULTRAFILTRATION PLANTS

Introduction

Ultrafiltration is a relatively new process which utilizes a hollow fiber membrane to remove undissolved, suspended or emulsified solids from water supplies without requiring coagulation. It is most generally used in specialized applications requiring extremely high purity water, as pretreatment prior to reverse osmosis or for removal of colloidal silica from boiler feed water. Application to potable water treatment would be limited to the production of extremely high quality water supplies of low turbidity (1 NTU or less) and with Fouling Indexes of less than 10.

The hollow fiber membrane which operates over a pressure range of 0.703 to 7.03 kg/cm^3 (10 to 100 psi) excludes particles larger than 0.01 μm (3.28 x 10^{-8} ft); but unlike reverse osmosis membranes, permits passage of inorganic salts and electrolytes. The hollow fiber membranes are contained in a pressure vessel or cartridge. During operation, the flow is introduced to the inside of the fiber. Filtrate or permeate collects on the outside of the membrane, concentrates at the end of the hollow fiber and is discharged to waste. In a typical single-pass application, 90% of the feed water is recovered as permeate. The membranes are cleaned by backflushing which restores the original porosity and allows continuous use for indefinite periods. In some applications a chlorine solution is added to the backflushing flow.

Impact of Raw Water Quality on Treatment Cost

Ultrafiltration membranes are sensitive to the concentration of suspended and colloidal solids in the feed water. The flux level (volume of permeate produced per unit area of membrane per day) and the flux stability are influenced by the feed water quality, the filtering cycle duration, and the quality of water used for backflushing the membranes. Where a water supply has a Fouling Index of 10 or less (typical of most groundwaters and high clarity surface waters), filtering cycles will range up to 8 hours with about a 10% reduction in flux. In general, capacity can be restored to nearly clean membrane values by a fastforward flush of influent to waste. However, after two or three flushings, the membranes must be backwashed to restore the initial flux level.

Higher suspended solids loadings will reduce the length of filtering cycles and require a higher percentage of the permeate for backflushing the membranes, thus increasing the unit cost of production. Since membrane unit production rates decrease during a filtering cycle, systems must be designed with an initial reserve capacity to meet continuous system supply demands adding to the capital cost of an ultrafiltration installation. The cost data which were developed assume a maximum 10% reduction in unit production at the termination of a filtration cycle.

Construction Costs

Table 52 provides conceptual design information which was used to develop the construction costs. The construction costs include skid-mounted ultrafiltration units containing the hollow-fiber membranes in cartridges, automatic and manual valves for backwashing and unit isolation, flow meters, pressure gauges, integral backwash pump, and control panel. A separate supply pump is included, as is all interconnecting piping serving plants with multiple units. The costs also include storage tanks and solution pumps for membrane cleaning. Housing is provided for ultrafiltration equipment and supporting appurtenances. Product water storage facilities are not included in the cost estimates.

TABLE 52. CONCEPTUAL DESIGNS FOR PACKAGE ULTRAFILTRATION PLANTS

Plant Capacity, gpd	Membrane Area, sq ft	Number of Treatment Modules	Housing Dimensions, LxWxH, ft	Housing Area, sq ft
2,100	30	1	10x10x10	100
30,000	424	1	15x15x10	225
100,000	1,431	3	22x17x10	374
250,000	3,604	4	33x20x10	660
500,000	7,155	8	40x34x10	1,360
1,000,000	14,310	16	70x40x10	2,800

Notes: 1. Plant capacity is the initial capacity with clean hollow fiber membranes.
2. Initial flux rate of approximately 70 gal/day/sq ft was used to size units.

Construction costs are presented in Table 53 and in Figure 44.

Operation and Maintenance Requirements and Costs

Process energy requirements were calculated using connected horsepower sizes recommended by manufacturers. Continuous 24 hr/day, 365 day/year operation with one backwash/day of 30 minute duration was assumed in the process energy calculations. The costs also reflect a forward-flushing of membranes at 8 hour intervals during a filtration cycle.

Maintenance material requirements are related to replacement of hollow fiber membrane cartridges once every 4 years, replacement of pump seals, small parts for chemical feed pumps and instruments, and for general facility operation. Membrane cleaning chemical costs are not included, but are discussed in the following section.

TABLE 53. CONSTRUCTION COST SUMMARY FOR PACKAGE ULTRAFILTRATION PLANTS

Cost Category	Membrane Area, sq ft 30	424	1,431	3,604	7,155	14,310
Excavation and Sitework	$ 1,300	$ 2,400	$ 4,100	$ 5,700	$ 10,200	$ 14,900
Manufactured Equipment	5,500	25,300	65,600	129,800	239,000	415,100
Concrete	1,800	3,700	5,800	10,200	16,700	28,800
Labor, Installation	1,100	5,200	13,500	26,900	49,500	85,900
Pipe & Valves	500	1,100	2,200	3,800	4,500	6,200
Electrical, Instrumentation	1,500	5,600	13,300	25,800	48,100	85,300
Housing	7,800	14,600	21,700	29,000	40,800	56,000
Subtotal	19,500	57,900	126,200	231,200	408,800	692,200
Design Contingencies	2,900	8,700	18,900	34,700	61,300	103,800
Total	$22,400	$66,600	$145,100	$265,900	$470,100	$796,000

Operation and maintenance requirements are summarized in Table 54 and illustrated in Figures 45 and 46.

TABLE 54. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE ULTRAFILTRATION PLANTS

Membrane Area, sq ft	Energy, kwh/yr Building	Process	Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
30	1,500	1,300	2,800	240	365	4,500
424	3,300	8,600	11,900	2,400	365	7,300
1,431	5,400	9,000	14,400	8,500	425	14,200
3,604	9,600	17,800	27,400	21,200	550	29,200
7,155	19,700	34,600	54,300	42,500	730	54,400
14,310	40,600	59,800	100,400	85,200	1,095	104,300

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

Chlorine is the only chemical used routinely in ultrafiltration systems. Chlorine is added to the backwash water at dosages ranging up to 50 mg/L to assist in cleaning the membranes. Table 55 presents expected chemical costs of ultrafiltration related to the use of chlorine.

TABLE 55. TYPICAL CHEMICAL COSTS FOR PACKAGE ULTRAFILTRATION PLANTS

Plant Capacity, gpd	Chlorine Usage, lb/yr	Chlorine Cost, $/yr
2,500	8	3
30,000	95	35
100,000	317	117
250,000	793	293
500,000	1,585	587
1,000,000	3,170	1,173

Notes: 1. Chlorine usage assumes one 30 minute duration backwash per day and chlorine dosage of 50 mg/L.
2. Chlorine cost is $0.37/lb.

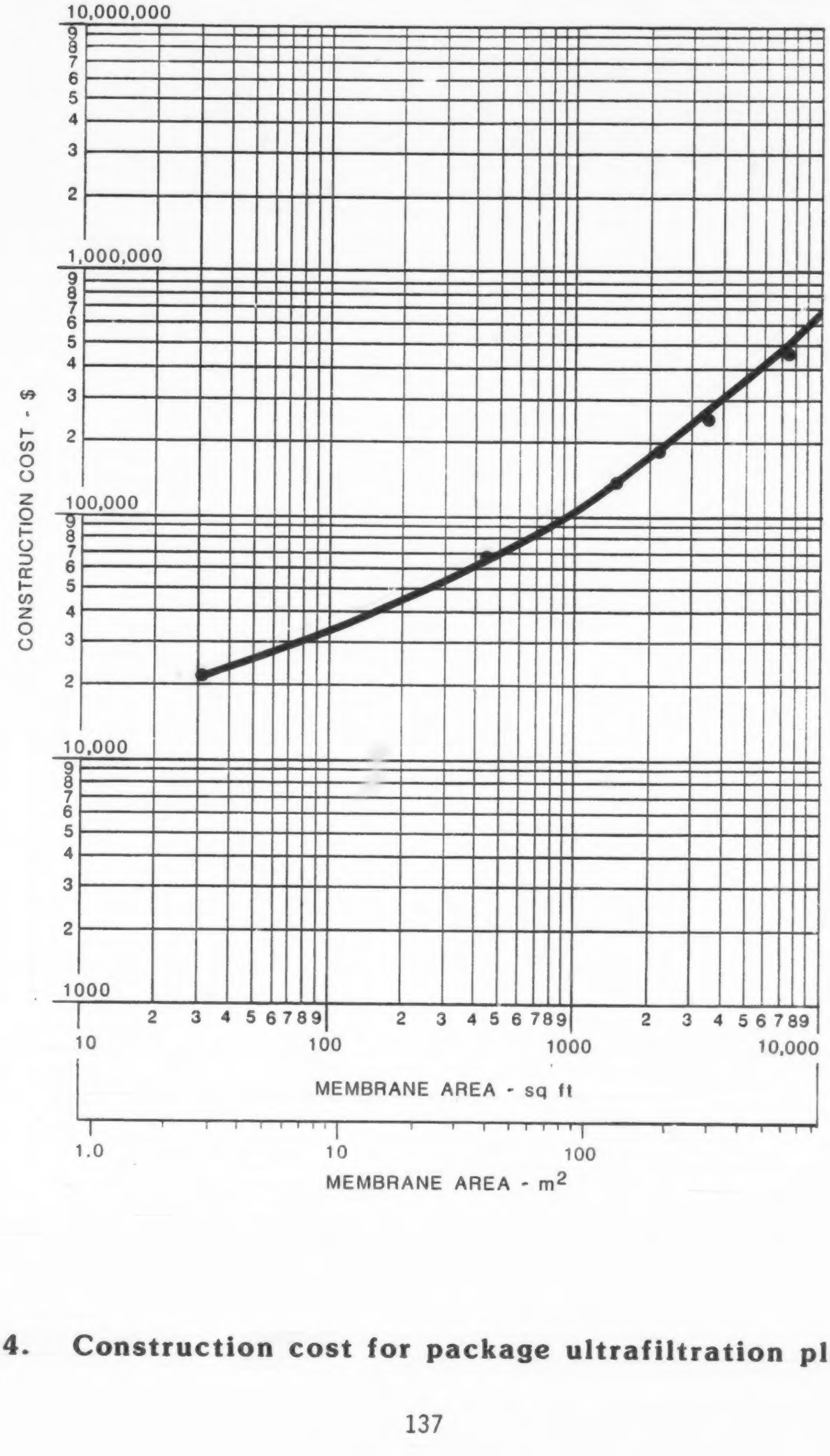


Figure 44. Construction cost for package ultrafiltration plants.

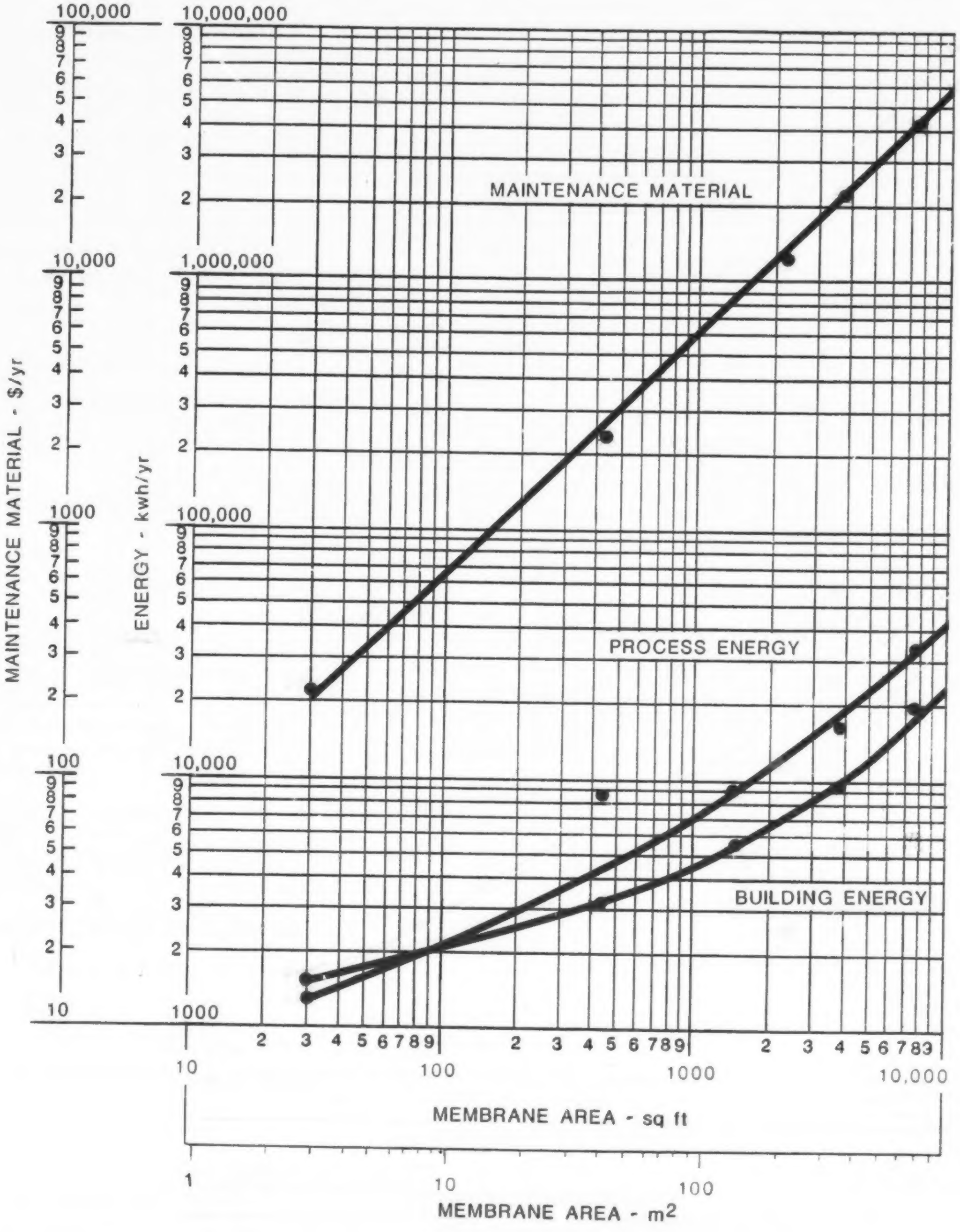


Figure 45. **Operation and maintenance requirements for package ultrafiltration plants - building energy, process energy, and maintenance material.**

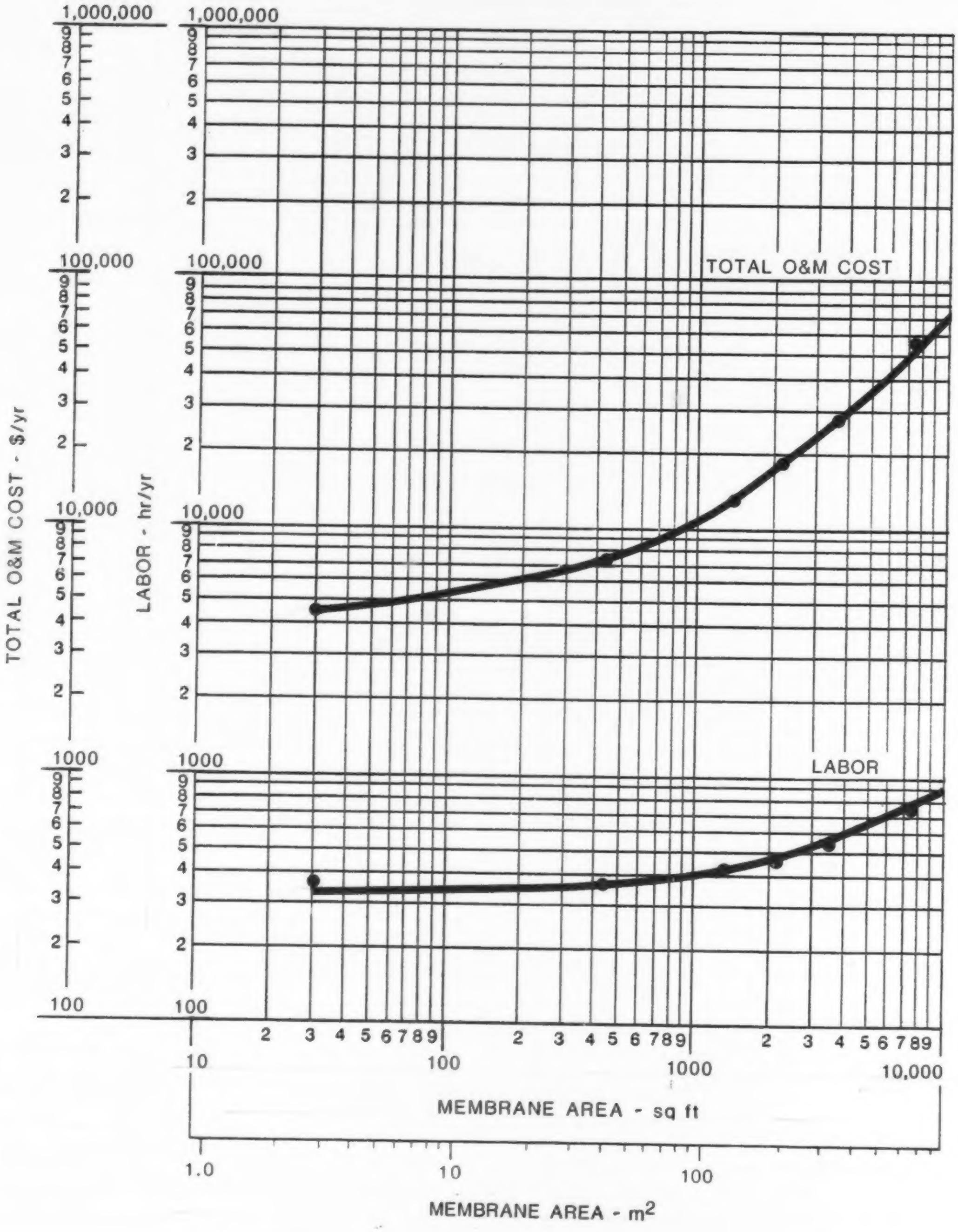


Figure 46. Operation and maintenance requirements for package ultrafiltration plants - labor and total O&M cost.

CATION EXCHANGE SOFTENING

Introduction

Ion exchange softening, in addition to its ability to remove hardness, is also capable of removing barium and radium. During treatment, sodium ions located on an exchange resin are replaced by hardness ions (principally calcium and magnesium), as well as barium and radium. At exhaustion or breakthrough of the resin, the exchanger is removed from service, and regenerated with a saturated sodium chloride solution. During regeneration, sodium ions from the regenerant displace hardness and other ions which have been exchanged on to the resin during the operating phase of the cycle, and these ions are subsequently displaced with the spent brine during the regeneration phase. A typical regeneration consists of an upflow backwash cycle, a downflow regeneration cycle with concentrated sodium chloride brine, and a downflow rinse cycle. Each of these cycles during the regeneration phase uses water which has not already been treated by ion exchange. Approximately 0.13 kg (0.29 lb) of sodium chloride regenerant is required for each 0.0649 kg (0.143 lb) of hardness (as $CaCO_3$) removed, which is equivalent to 2.03 kg of sodium chloride per kg of hardness removed. The quantity of wastewater produced during the regeneration process depends upon the amount of hardness which is removed from the feed water. Typical quantities of regenerant and wastewater are about 6% of the feed if 200 mg/L as $CaCO_3$ of hardness is removed, and about 18% if 600 mg/L is removed.

Impact of Raw Water Quality on Treatment Cost

Hardness--

Hardness is the typical design parameter for ion exchange softening units. As the quantity of hardness which must be removed increases, the frequency of regeneration increases. Increased regeneration frequency increases each of the following: regenerant chemical use; labor requirements; volume of regenerant brine and wastewater produced; and downtime for regeneration. These increased requirements result in higher operation and maintenance costs.

Other Inorganics--

For barium and radium, the percentage removal of each appears to exceed the percentage removal of hardness. Barium removal investigations by Sorg and Logsdon, indicate that near the exhaustion point of the exchange resin, 70% of the barium was being removed when only 38% of the hardness was being removed.[1] Comparing results at two ion exchange plants with different raw water barium concentrations indicated a slight increase in product water barium concentration as the raw water concentration increases. This does not appear to be significant, however, since blending with untreated water would normally be practiced, and the key factor is the volume of water treated prior to regeneration.

Radium removal has been studied by Singley, et al This study indicated slightly better removal of radium than calcium or magnesium, but no significant correlation was noted between raw water concentration and product water concentrations.[2] At properly operated plants, the percentage removal of barium was in the range of 95 to 97%, with barium removals of 85% noted even after hardness breakthrough had occurred.

On the basis of these two references, it appears that hardness would be the controlling design parameter in the majority of situations requiring removal of both hardness and barium or radium.

Construction Costs

Construction costs were developed for pressure ion exchange units with volumes between 0.085 and 14.7 m^3 (3 and 520 cu ft). Each system consists of two pressure ion exchange tanks, a brine tank (contains saturated sodium chloride brine), and an automatic regeneration system. The exchange tanks are designed for 50% freeboard during backwash and have a baked phenolic epoxy lining on the interior. The automatic regeneration system is activated by an increase in the product water hardness, but a lockout is provided to prevent both tanks from being regenerated at the same time. The automatic regeneration system terminates each cycle of the regeneration at a preset time. The brine tank is made of polyethelyene and fills with water automatically using a float valve. In order to have a saturated brine solution for regeneration, the brine tank must always contain some undissolved sodium chloride.

Conceptual designs which were used to estimate costs are shown in Table 56. For total resin volumes less than 5.3 m^3 (188 cu ft), salt is delivered in 22.7 or 36.3 kg (50 or 80 lb) bags, and added manually to the brine tank. For these plants, seven days of salt storage is provided. For total resin volumes of 5.3 m^3 (188 cu ft) and larger, salt is delivered in 22.68 metric ton (25 ton) bulk loads. Storage is provided in a below ground storage basin, which is either beneath the building housing the ion exchange units, or adjacent to it. A typical layout for an ion exchange softening plant is shown in Figure 47.

TABLE 56. CONCEPTUAL DESIGNS FOR CATION EXCHANGE SOFTENING

Total Resin Volume, cu ft	Softener Tanks		Housing	
	Number	Diameter, ft	LxWxH, ft	Area, sq ft
3	2	1.0	9x8x10	72
6	2	1.33	10x9x10	90
30	2	2.5	14x10x10	140
54	2	3.5	15x10x10	150
188	2	6.0	20x13x14	260
330	2	8.0	24x15x14	360
520	2	10.0	28x17x14	476

Note: For total resin volumes of 188, 330, and 520 cu ft, a below ground, concrete storage basin is used for salt storage and brine make-up. The basin is 25ftx25ftx6ft.

Regeneration is performed automatically in response to increases in product water hardness concentration. A typical regeneration consists of an upflow backwash, a down flow regeneration and a downflow rinse. The duration of each stage is controlled by an automatic timer. Raw water is used for each stage of regeneration, and assuming sufficient raw water pressure, the only pumping required is for the larger plants which have below ground brine tanks. Concentrated brine is removed from the brine tank or storage basin using a pump.

Construction costs are presented in Table 57 and in Figure 48.

Operation and Maintenance Requirements and Costs

For total resin volumes less than 5.3 m^3 (188 cu ft), no process energy is required since the entire regeneration cycle is performed using raw (unsoftened) water, which is pressurized. Larger plants use a below ground brine tank, and brine pumping is required during brine contact (regeneration) cycle of backwash. There is generally less than 0.35 kg/cm^2 (5 psi) head loss in the exchange unit, and this will usually eliminate the need for pumping after treatment. Building energy for heating, ventilation and lighting is 156 kwh/m^2/y (14.5 kwh/sq ft/yr), for 3.05 m (10 ft) high buildings and 209.8 kwh/m^2/y (19.5 kwh/sq ft/yr) for 4.3 m (14 ft) high buildings. These requirements are based upon an average lighting requirement of three hours per day.

Maintenance materials required include periodic make-up of resin, and miscellaneous replacement components for the exchanger, the valving, and the brine tank. Resin loss was estimated to be 3% per year for regeneration every fourth day, 6% for regeneration every other day, and 10% for daily regeneration. Resin costs are \$2,470/m^3 (\$70/cu ft).

Labor is required for addition of salt to the brine tank. At smaller plants the salt is delivered in either 22.7 or 36.3 kg (50 or 80 lb) bags, and must be manually added to the brine tank. In larger plants, salt is delivered in bulk, and operator attention is required to assure proper delivery to the brine storage tank. The operator should also check the exchange unit daily in order to assure that it is operating satisfactorily, and run a hardness test daily.

A summary of operation and maintenance requirements is presented in Table 58, and also in Figures 49 and 50.

Typical Chemical Requirements and Costs

Required salt quantities are a function of the plant flow rate and the quantity of hardness removed. The cost of salt varies widely with geographic location and the quantity purchased at a given time. Estimates of salt requirements and annual salt costs are shown in Table 59. Also shown in Table 59 is a formula which can be used to calculate salt costs for other plant flow rates and hardness removal rates.

TABLE 57. CONSTRUCTION COST SUMMARY FOR CATION EXCHANGE SOFTENING

Cost Category	Total Resin Volume, cu ft						
	3	6	30	54	188	330	520
Excavation and Sitework	$ 2,300	$ 2,300	$ 2,300	$ 2,300	$ 5,000	$ 5,000	$ 5,000
Manufactured Equipment	2,300	3,100	8,400	15,400	35,300	67,400	87,700
Concrete	200	300	400	500	6,200	6,600	6,600
Steel	--	--	--	--	7,800	7,800	7,800
Labor, Installation	800	800	800	1,000	11,700	12,100	12,100
Pipe and Valves	800	800	800	1,000	2,700	3,200	3,200
Electrical, Instrumentation	2,100	2,100	2,100	2,100	2,100	2,100	2,100
Housing	5,600	6,900	10,100	10,800	18,700	24,500	27,600
Subtotal	14,100	16,300	24,900	33,100	89,500	128,700	152,100
Design Contingencies	2,100	2,500	3,700	5,000	13,400	19,300	22,800
Total	$16,200	$18,800	$28,600	$38,100	$102,900	$148,000	$174,900

TABLE 58. OPERATION AND MAINTENANCE SUMMARY FOR CATION EXCHANGE SOFTENING

Total Resin Volume, cu ft	Energy, kwh/yr Building	Energy, kwh/yr Process	Energy, kwh/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
Rengeneration Frequency = daily						
3	1,100	---	1,100	200	190	2,400
6	1,300	---	1,300	200	200	2,500
30	2,100	---	2,100	500	220	3,100
54	2,200	---	2,200	800	250	3,700
188	5,100	100	5,200	2,200	200	4,800
330	7,000	100	7,100	3,900	210	6,700
520	9,300	100	9,400	5,600	220	8,700
Regeneration Frequency = 2 days						
3	1,100	---	1,100	100	100	1,300
6	1,300	---	1,300	200	100	1,400
30	2,100	---	2,100	400	110	1,800
54	2,200	---	2,200	700	120	2,200
188	5,100	100	5,200	1,700	100	3,200
330	7,000	100	7,100	3,000	110	4,700
520	9,300	100	9,400	4,200	110	6,100
Regeneration Frequency = 4 days						
3	1,100	---	1,100	100	50	700
6	1,300	---	1,300	200	50	900
30	2,100	---	2,100	300	60	1,100
54	2,200	---	2,200	500	70	1,400
188	5,100	100	5,200	1,300	50	2,200
330	7,000	100	7,100	2,300	50	3,400
520	9,300	100	9,400	3,100	50	4,300

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Field Data Collection

At German Valley, Illinois, aeration, gravity filtration, and ion exchange softening are utilized. The purpose of the softening is to remove hardness, and the exchangers are regenerated approximately every two days. There are two ion exchange units, with a total resin volume of 1.26 m^3 (45 cu ft).

TABLE 59. TYPICAL CHEMICAL COSTS FOR CATION EXCHANGE SOFTENING

	Hardness Removed, mg/L as $CaCO_3$					
	200		400		600	
Average Plant Flow Rate, gpd	Salt, tons/yr	Cost, $/yr	Salt, tons/yr	Cost, $/yr	Salt, tons/yr	Cost, $/yr
4,000	2.5	240	4.9	470	7.4	700
10,000	6.2	600	12.4	1,200	18.5	1,800
40,000	24.7	2,000	49	3,900	74	5,900
100,000	52	4,200	124	9,900	185	14,800
400,000	247	17,300	494	34,600	742	51,900
1,000,000	618	43,300	1,236	86,500	1,855	129,900

Notes:
1. Salt requirements are based upon 0.29 lb/kilograin of hardness removed, which is equivalent to 2.03 lb of salt per lb of hardness removed.
2. Salt costs are: $95/ton for less than 20 tons/yr
   $80/ton between 20 and 200 tons/yr
   $70/ton for greater than 200 tons/yr
3. Salt cost for other hardness removals may be calculated using the formula:

$$\$/\text{yr} = 3.0898\ (\text{mg/L hardness removed})(\text{salt cost/ton})(Q)$$

where Q = plant flow rate in mgd

$$3.0898 = \frac{8.34(365\ \text{day/yr})(2.03\ \text{lb salt/lb hardness removed})}{2{,}000\ \text{lb/ton}}$$

A comparison of the operation and maintenance requirements allocated to ion exchange softening and Figures 49 and 50 is shown following:

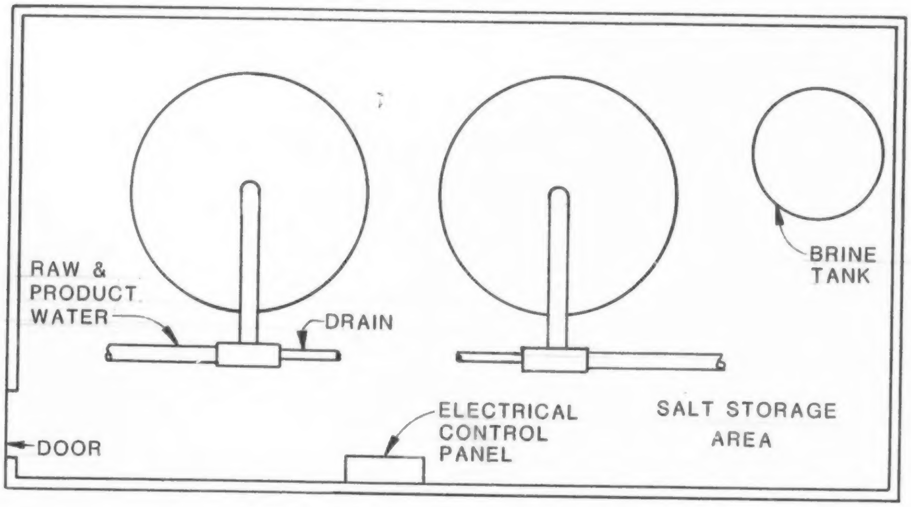
	Field Data	Data From Figures 49 and 50
Electrical Energy, kwh/hr		
Process	-	-
Building	-	2,100
Total	2,600	2,100
Maintenance Material, $/yr	50	550
Labor, hr/yr	94	105

With the exception of maintenance material, field data and data from Figures 49 and 50 match closely. There is no apparent explanation for the difference in maintenance material data.

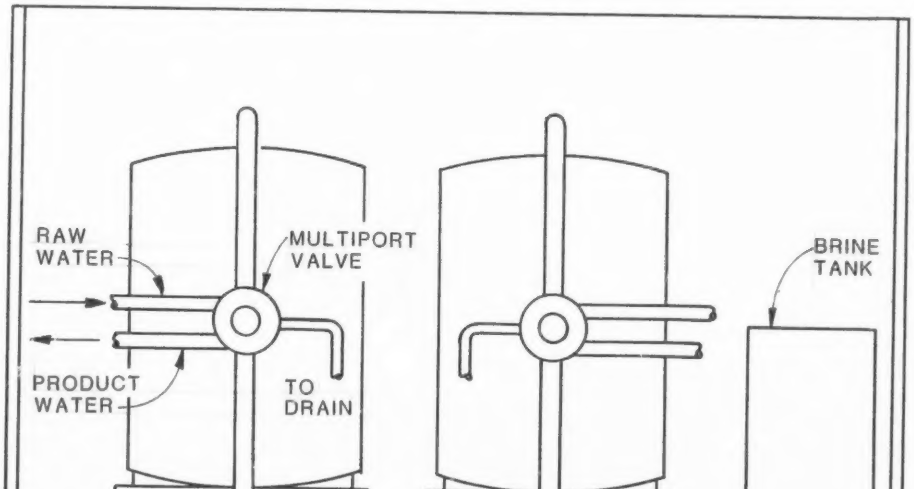
References

1. Sorg, T. J., and Logsdon, G. S., "Treatment Technology to Meet the Interim Primary Drinking Water Regulations," Journal AWWA, July 1980, p. 411.

2. Singley, J.E., et al, "Costs of Radium Removal From Potable Water Supplies," U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-600/2-77-073, April 1977.


RAW &
PRODUCT
WATER
DRAIN
BRINE
TANK
ELECTRICAL
CONTROL
PANEL
SALT STORAGE
AREA
DOOR

PLAN VIEW


RAW
WATER
MULTIPORT
VALVE
BRINE
TANK
PRODUCT
WATER
TO
DRAIN

ELEVATION VIEW

Figure 47. Typical cation exchange softening installation.

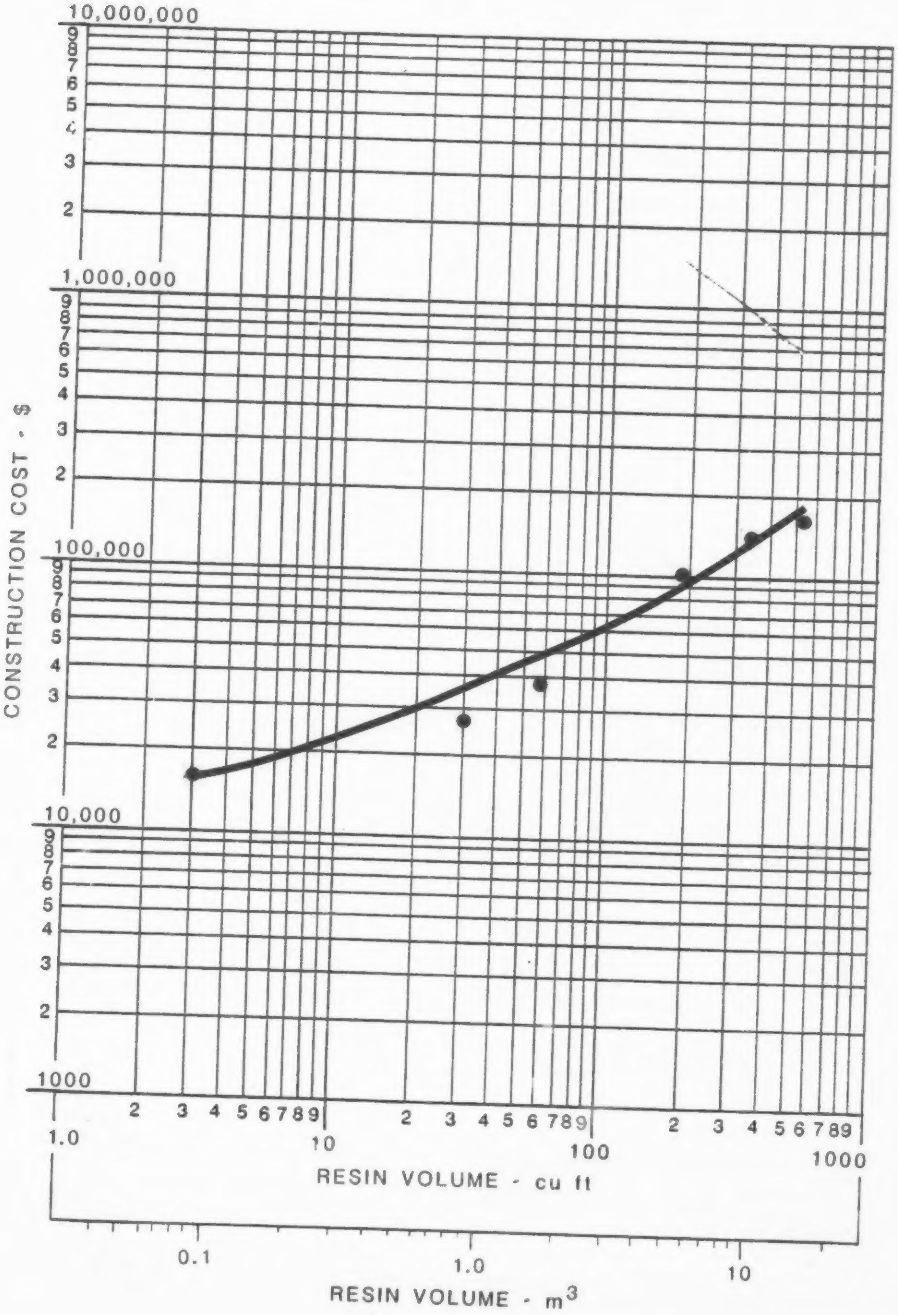


Figure 48. Construction cost for cation exchange softening.

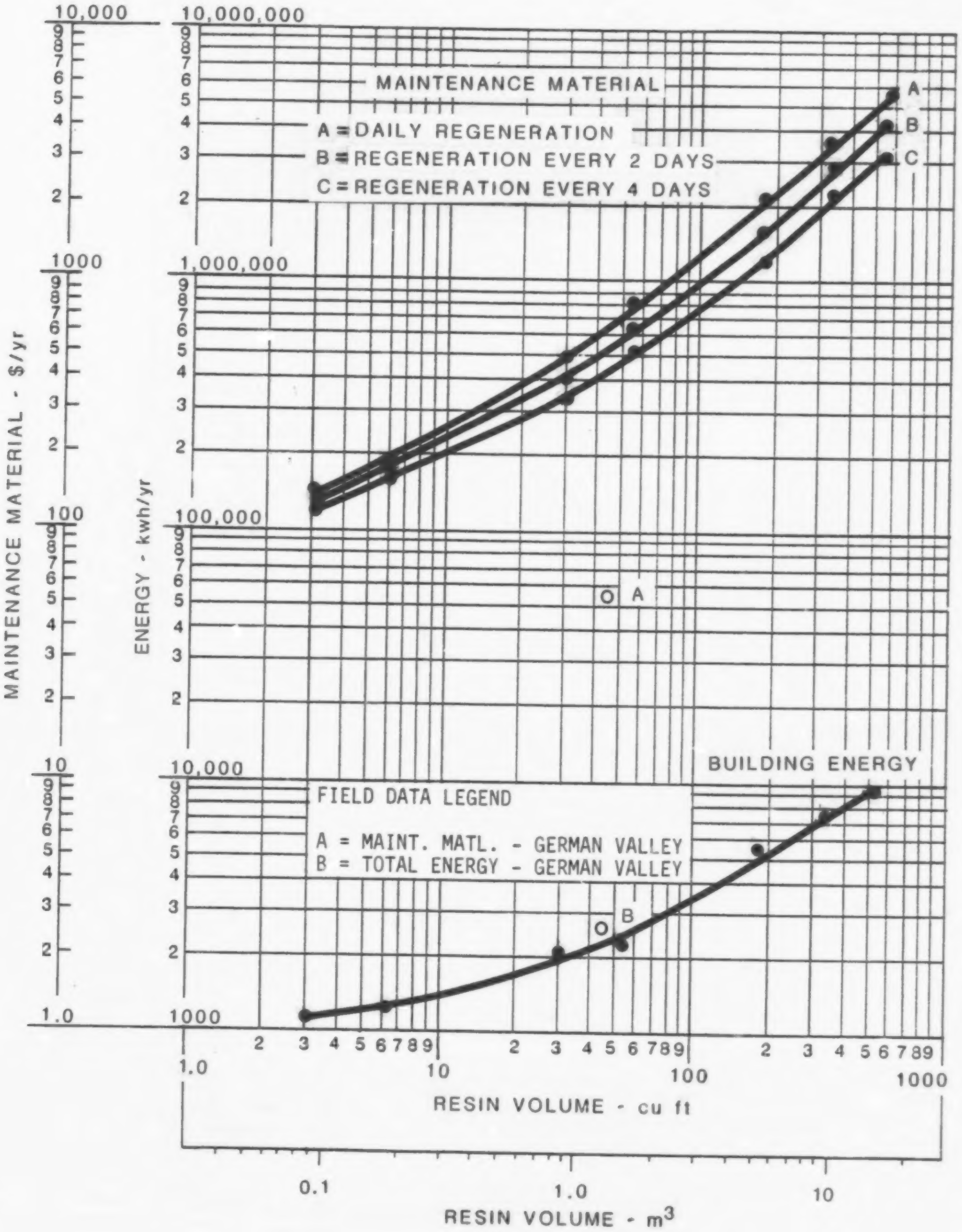


Figure 49. **Operation and maintenance requirements for cation exchange softening - building energy and maintenance material.**

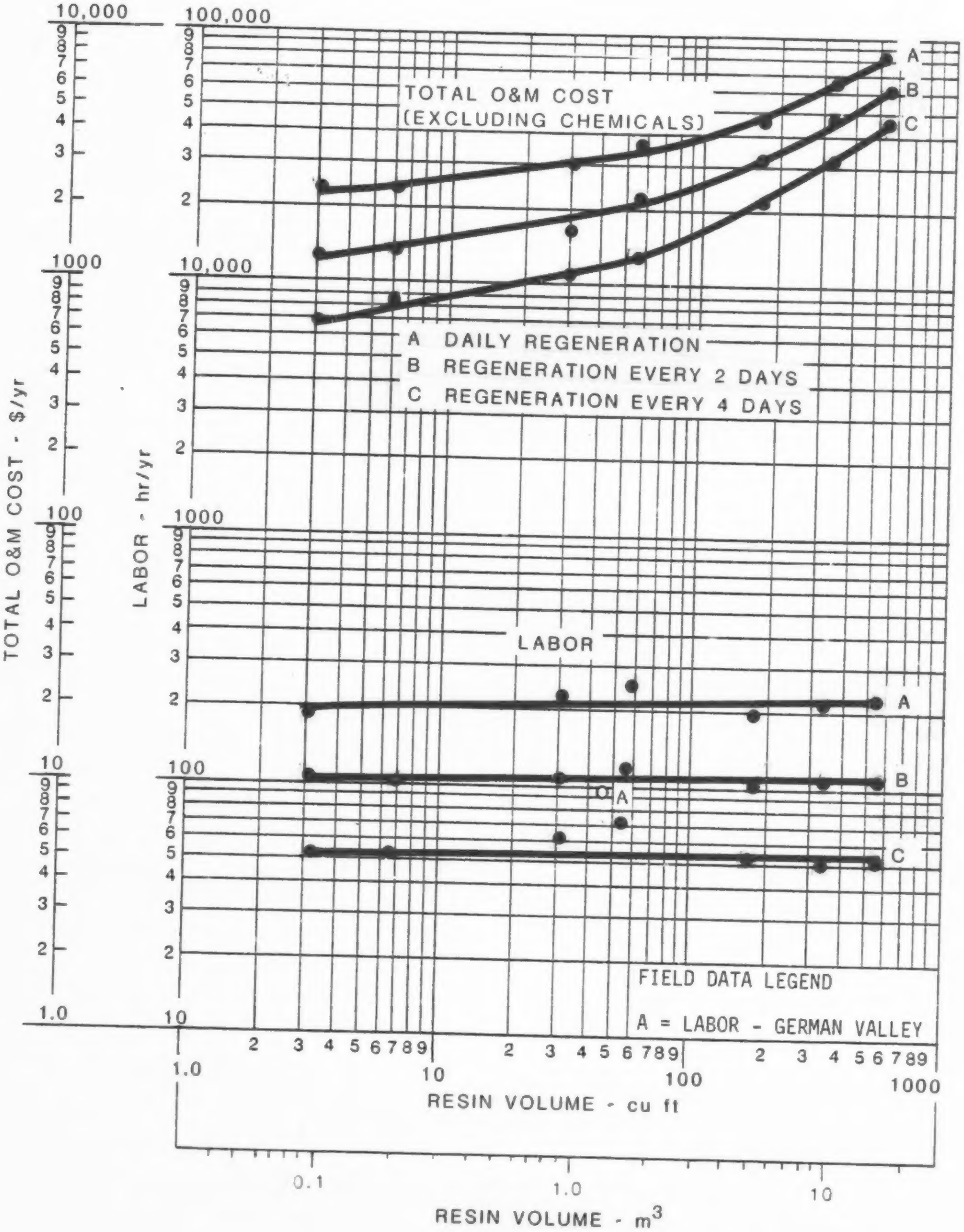


Figure 50. **Operation and maintenance requirements for cation exchange softening - labor and total O&M cost.**

ANION EXCHANGE NITRATE REMOVAL

Introduction

Strong base resins are capable of nitrate removal by exchanging chloride ions for nitrate ions. Exhausted resin is regenerated with a strong (6-12%) sodium chloride brine. The quantity of wastewater produced during the regeneration process varies with the frequency of regeneration, which is influenced by the nitrate and sulfate concentrations. Typical values for wastewater are 4% of the feedwater for 20 mg/L of nitrate (as N) and 50 mg/L of sulfate, and 5.6% for 50 mg/L of nitrate (as N) and 100 mg/L of sulfate.

Impact of Raw Water Quality on Treatment Cost

Three key characteristics of the raw water which affect nitrate removal are the nitrate, sulfate, and total anion concentrations. Sulfate concentration is important because sulfate is selectively removed before nitrate. This is an important factor for two reasons. First, increased sulfate concentrations will decrease the nitrate exchange capacity of the resin, assuming no change in total anion concentration. Secondly, if a resin is operated beyond its exhaustion point for nitrate removal, sulfate ions will displace nitrate ions from the resin, and the exchanger product water will contain a higher nitrate concentration than the raw water feed. The total anion concentration is important, because a decrease in the ratio of nitrate ions to total anions results in a decrease in the nitrate exchange capacity of the resin.

Table 60 illustrates the variation of nitrate exchange capacity as a function of nitrate and sulfate concentrations. These exchange capacities are based upon a total anion concentration equivalent to two times the sum of the nitrate and sulfate ion concentrations.

TABLE 60. NITRATE EXCHANGE CAPACITY AS A FUNCTION OF FEEDWATER NITRATE AND SULFATE CONCENTRATION (kilograins/cu ft, as $CaCO_3$)

Sulfate Concentration, mg/L	Nitrate Concentration as N, mg/L		
	20	50	100
50	8.7	11.0	12.0
100	6.7	9.0	11.0

Note: Total anions are twice the sum of the sulfate plus nitrate (as NO_3).

Iron, suspended solids, and organics must be present in low concentrations for proper operation of the exchanger. Pretreatment is recommended for iron concentrations greater than 0.1 mg/L, suspended solids greater than 2 NTU, and organics at any measurable concentration.

Construction Costs

Costs were developed for pressure ion exchange units with volumes ranging from 0.11 to 14.7 m^3 (4 to 520 cu ft), using conceptual design information presented in Table 61. These volumes are adequate for treatment of flows up to 3,785 m^3/d (1 mgd) and nitrate concentrations up to 50 mg/L as N, assuming the sulfate concentration is less than 100 mg/L.

The ion exchange tanks have a baked phenolic epoxy lining on the interior, and were designed for 50% freeboard during backwash. Each system consists of two exchange tanks, and the units can be regenerated either manually or automatically. For systems with a total resin volume less than 0.84 m^3 (30 cu ft) a polyethylene tank is used to make the saturated brine solution using manual addition of salt from 36.3 kg (80 lb) bags. Larger plants use an underground brine tank, with the salt delivery in bulk directly to the brine tank.

Construction costs are presented in Table 62 and in Figure 51.

Operation and Maintenance Requirements and Costs

Regeneration frequency is a function of the volume of resin, the nitrate exchange capacity of the resin, average plant flow rate, and nitrate ion concentration. The following formula can be used to calculate regeneration frequency.

$$\text{Regeneration frequency} = \frac{\text{(Constant)(Resin Vol)(Ex Cap)}}{\text{(Flow)(Nitrate Conc)}}$$

where: Constant = 0.004794
Resin Vol = Resin volume in cu ft
Ex Cap = Nitrate exchange capacity of resin in kilograins/cu ft, as $CaCO_3$
Flow = Average plant flow, mgd
Nitrate Conc = Nitrate concentration, mg/L as N

Regeneration consists of an upflow backwash at 4.88 to 7.32 $m^3/m^2/h$ (2 to 3 gpm/sq ft) for 10 minutes, downflow regeneration with a 10-12% sodium chloride brine at a rate of 1.11 L/s/m^3 (0.5 gpm/cu ft) of resin for approximately 10 minutes, and a downflow rinse at 4.46 L/s/m^3 (2 gpm/cu ft) of resin. Regeneration sodium chloride requirements are 240 kg/m^3 (15 lb/cu ft) of resin. The upflow backwash and downflow rinse steps are performed with raw water, and sufficient raw water pressure was assumed to be available without the need for pumping.

Process energy is required only for brine pumping during the regeneration step. Because there is generally less than 0.35 kg/cm^3 (5 psi) head loss in the exchange unit, pumping after treatment will not normally be required. Building energy for heating, ventilation, and lighting is 156 kwh/m^2/y (14.5 kwh/sq ft/yr) for 3.05 m (10 ft) high buildings and 209.8 kwh/m^2/y (19.5 kwh/sq ft/yr) for 4.27 m (14 ft) high buildings. Lighting energy is based upon an average requirement of three hours per day.

TABLE 61. CONCEPTUAL DESIGNS FOR ANION EXCHANGE NITRATE REMOVAL

Total Resin Volume, cu ft	Ion Exchange Tanks		Resin Depth, ft	Housing		Brine Storage Basin LxWxH, ft
	Number	Diameter, ft		LxWxH, ft	Area, sq ft	
4	2	1.0	2.6	9x8x10	72	---
17	2	2.0	2.7	13x10x10	130	---
54	2	3.5	2.8	15x10x10	150	25x25x6
188	2	6.0	3.3	20x13x14	260	25x25x6
280	2	7.5	3.2	23x14x14	322	25x25x6
520	2	10.0	3.3	28x17x14	476	30x30x6

TABLE 62. CONSTRUCTION COST SUMMARY FOR ANION EXCHANGE NITRATE REMOVAL

Cost Category	Total Resin Volume, cu ft					
	4	17	54	188	280	520
Excavation and Sitework	$ 2,100	$ 2,100	$ 4,400	$ 4,400	$ 4,400	$ 5,300
Manufactured Equipment	3,100	8,600	23,100	64,100	96,800	164,800
Concrete	300	400	5,500	5,800	6,000	8,400
Steel	--	--	7,800	7,800	7,800	10,900
Labor, Installation	400	1,100	12,100	12,800	12,900	17,200
Pipe and Valves	800	800	1,000	2,600	2,600	3,100
Electrical, Instrumentation	3,100	3,100	3,100	3,100	3,100	3,100
Housing	5,600	9,600	11,100	16,600	19,200	25,000
Subtotal	15,400	25,700	58,100	117,200	152,800	237,800
Design Contingencies	2,300	3,900	10,200	17,600	22,900	35,700
Total	$17,700	$29,600	$78,300	$134,800	$175,700	$273,500

Note: Resin cost is included in manufactured equipment category.

Maintenance material required includes periodic make-up of resin, and miscellaneous replacement components for the exchanger, the valving, and the brine tank. Resin loss was estimated to be 20%/yr for regeneration twice a day, 10%/yr for daily regeneration, and 5%/yr for regeneration every other day. In addition, complete replacement of the resin every five years was assumed. Resin costs used were $7,410/m^3 ($210/cu ft).

Labor is required for addition of salt to the brine tank. At smaller plants the salt is delivered in either 22.7 or 36.3 kg (50 or 80 lb) bags, and must be manually added to the brine tank. In larger plants, salt is delivered in bulk, and operator attention is required to assure proper delivery to the brine storage tank. Labor requirements decrease when salt delivery is in bulk, as can be observed in Table 63 for the three largest plants. The operator must also check the exchange unit daily in order to assure that it is operating satisfactorily. Nitrate testing should be conducted at least daily by the operator. An even better approach is to use instrumentation for continuous readout of nitrate concentration.

A summary of operation and maintenance requirements and costs is presented in Table 63, and in Figures 52 and 53.

Typical Chemical Requirements and Costs

Table 64 presents sodium chloride requirements and costs, based upon salt costs as noted. Sodium chloride costs vary widely throughout the country, and these costs are presented as typical, and should be adjusted to meet local cost conditions.

Field Data Collection

At McFarland, California, anion exchange is used to remove nitrate from a groundwater supply. There are three ion exchange units with a total resin volume of 11.88 m^3 (424.2 cu ft). A comparison of the actual construction cost and the projected operation and maintenance requirements with Figures 51, 52, and 53 is shown following:

	Field Data	Data From Figures 51, 52 and 53
Construction Cost	$276,700	$230,000
Electrical Energy, kwh/hr		
Process	-	800
Building	-	8,000
Total	56,520	8,800
Maintenance Material, $/yr	12,600	30,000
Labor, hr/yr	-	280

Construction costs for the recently completed plant at McFarland are comparable to Figure 51. The discrepancy in total electrical requirements is due to different methods used to calculate process electrical. The field data is based upon additional energy required to compensate for headloss through the

TABLE 63. OPERATION AND MAINTENANCE SUMMARY FOR ANION EXCHANGE NITRATE REMOVAL

Total Resin Volume, cu ft	Energy, kwh/yr Building	Energy, kwh/yr Process	Energy, kwh/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
Regeneration Frequency = 2 per day						
4	1,100	---	1,100	500	390	4,900
17	1,900	100	2,000	1,700	480	7,100
54	2,200	200	2,100	5,100	390	9,600
188	5,100	600	5,700	17,300	450	22,700
280	6,300	900	7,200	25,700	490	31,600
520	9,300	1,700	11,000	47,200	590	54,500
Regeneration Frequency = daily						
4	1,100	---	1,100	400	200	2,700
17	1,900	---	1,900	1,400	240	4,200
54	2,200	100	2,300	4,000	200	6,400
188	5,100	300	5,400	13,300	220	16,100
280	6,300	500	6,800	19,800	250	23,000
520	9,300	900	10,200	36,300	300	40,300
Regeneration Frequency = 2 days						
4	1,100	---	1,100	400	100	1,600
17	1,900	---	1,900	1,200	120	2,700
54	2,200	100	2,300	3,400	100	4,700
188	5,100	200	5,300	11,300	110	12,900
280	6,300	300	6,800	16,800	120	18,600
520	9,300	400	9,700	30,800	150	33,100

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 64. TYPICAL CHEMICAL COSTS FOR ANION EXCHANGE NITRATE REMOVAL

Average Flow Rate, gpd	Sulfate, mg/L	Salt Requirement, tons/yr Nitrate, mg/L as N			Salt Cost, $/yr Nitrate, mg/L as N		
		20	50	100	20	50	100
4,000	50	5.3	10.4	19.0	500	1,000	1,800
	100	6.8	12.7	20.8	650	1,200	2,000
10,000	50	13.1	26.0	47.6	1,300	2,100	3,800
	100	17.0	31.7	51.9	1,600	2,500	4,200
40,000	50	53	104	190	4,300	8,300	15,200
	100	68	127	210	5,500	10,200	14,700
100,000	50	130	260	480	10,400	18,200	33,600
	100	170	320	520	13,600	22,400	36,400
400,000	50	530	1,040	1,900	37,100	72,800	133,000
	100	680	1,270	2,080	47,600	88,900	145,600
1,000,000	50	1,310	2,600	4,760	91,700	182,000	333,200
	100	1,700	3,170	5,190	119,000	221,900	363,300

Notes: 1. Salt requirements are based upon a requirement of 15 lb/cu ft of resin/regeneration, the feed water nitrate concentration shown, and the nitrate exchange capacities presented in Table 60.

2. Salt costs used in this table are: $95/ton for less than 20 tons/yr
$80/ton between 20 and 200 tons/yr
$70/ton for greater than 200 tons/yr

ion exchange vessels. Process energy requirements in Figure 52 are based upon sodium chloride brine pumping only, and do not include the energy equivalent of the headloss through the exchangers.

Maintenance material estimates in Figure 52 include 10% annual attrition of the resin plus complete replacement of the resin every 5 years; a resin cost of \$7,500/m^3 (\$210/cu ft) was used. The field data does not include the cost of complete resin replacement after 5 years, and used a resin cost of only \$4,855/m^3 (\$137/cu ft). Adjusting the field data to incorporate complete resin replacement every 5 years increases the projected maintenance material cost to \$24,300/yr. The field data do not include a labor cost, as no new employees were added when the plant was put on-line, which in part was possible because a full-time EPA research technician is present during the first year of operation.

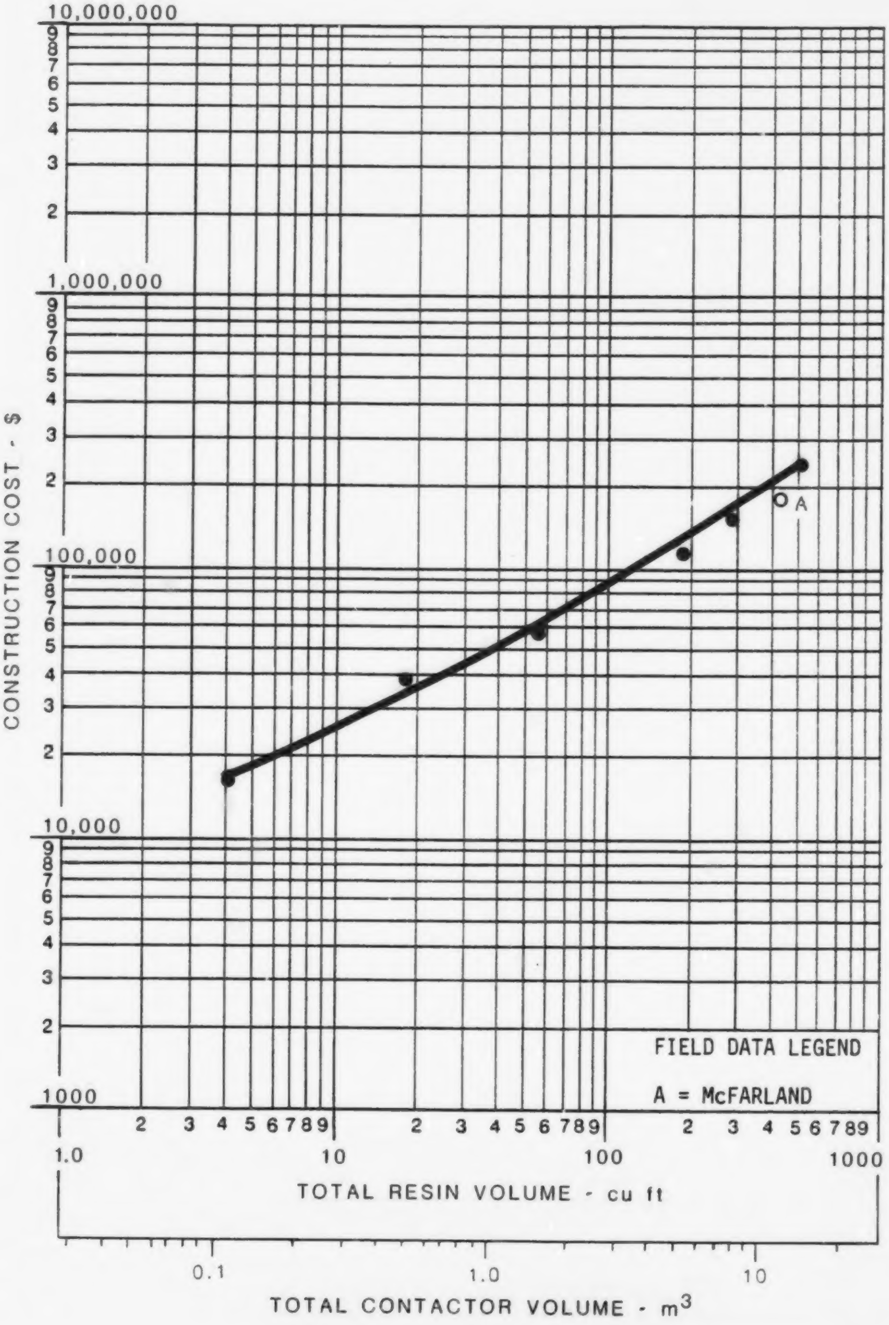


Figure 51. **Construction cost for anion exchange nitrate removal.**

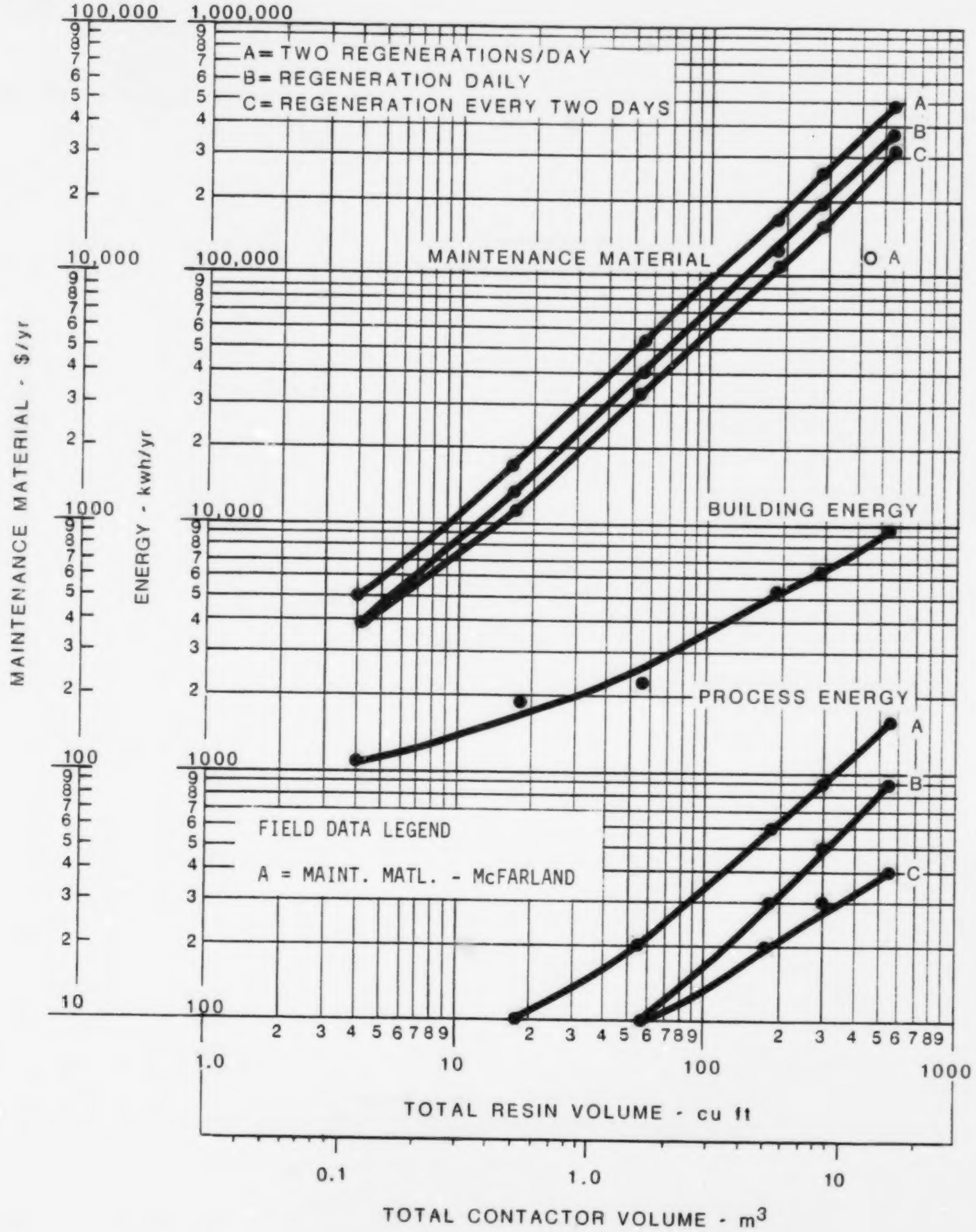


Figure 52. **Operation and maintenance cost for anion exchange nitrate removal - building energy, process energy, and maintenance material.**

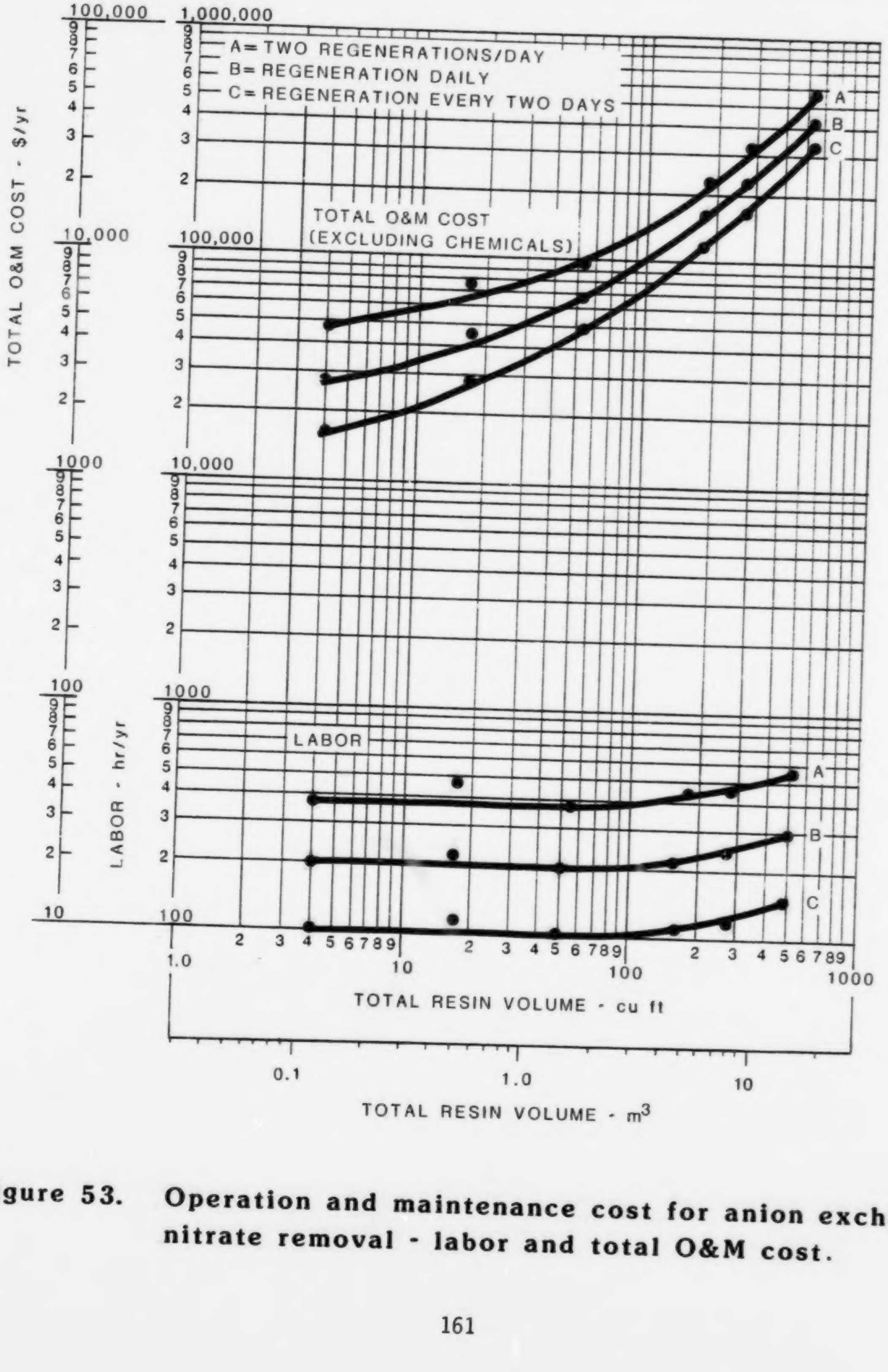


Figure 53. **Operation and maintenance cost for anion exchange nitrate removal - labor and total O&M cost.**

ACTIVATED ALUMINA FLUORIDE REMOVAL

Introduction

Fluoride removal from water supplies can be accomplished using granular activated alumina as a reversible adsorption medium. Successful and cost-effective operation depends upon adjustment of the feed water pH to, or near to, the optimum pH for adsorption of the fluoride ion by the activated alumina. A second factor instrumental in successful operation is regeneration of the exhausted bed to its original state.

The basic principles of fluoride removal technology were optimized by Rubel.[1,2,3] In this approach, the fluoride removal operation is divided into four distinct stages: treatment; backwash; regeneration; and neutralization. A basic description of each stage and the principal design paramenters are as follows:

Treatment Cycle - The most important consideration is adjustment of feed water pH to 5.5, which is optimum for most waters. At this pH, fluoride removal capacities between 3.44 and 9.17 kg/m^3 (1,500 to 4,000 grains/cu ft) have been experienced. Operation at pH 6.0 or greater will substantially reduce the exchange capacity, resulting in shorter treatment runs and more frequent regeneration. Raw water feed rate should be 12.2 $m^3/m^2/h$ (5 gpm/sq ft). In the initial stage of the treatment cycle, product water concentrations as low as 0.1 mg/L of fluoride are produced, but these concentrations gradually increase throughout the treatment cycle.

Backwash Cycle - An upflow backwash is necessary to reverse bed packing which occurs during treatment, as well as to remove suspended solids which are deposited in the bed during treatment. Backwash rates between 19.5 and 22.0 $m^3/m^2/h$ (8-9 gpm/sq ft) produce 50% bed expansion, but care should be taken to assure that activated alumina is not backwashed out of the contactor. Ten minutes is a normal backwash time, unless there has been fouling of the alumina, such as with iron compounds.

Regeneration Cycle - The regeneration cycle consists of three stages: (1) upflow regeneration; (2) upflow rinse; and (3) downflow regeneration. Flow rates and typical durations of these stages are:

	Flow Rate	Typical Duration
Upflow Regeneration	6.1 $m^3/m^2/h$ (2.5 gpm/sq ft)	35 min
Upflow Rinse	12.2 $m^3/m^2/h$ (5.0 gpm/sq ft)	30 min
Downflow Regeneration	6.1 $m^3 3/^2/h$ (2.5 gpm/sq ft)	35 min

The regenerant utilized is sodium hydroxide, at a concentration of one percent by weight.

Neutralization Cycle - Raw water at pH 2.5 is introduced into the top of the bed. Effluent pH is monitored, and when it has decreased to satisfactory levels, the raw water pH is adjusted to 5.5 and the next run commences.

These principles were used to develop costs for the removal of fluoride by activated alumina. Other methods which are slightly different can also be used to accomplish the same results.

During treatment, blending of product water from a contactor nearing exhaustion (often times exceeding the MCL) with product water from a newly regenerated contactor will result in maximum utilization of resin exchange capacity, while still producing a water which meets the MCL. Also, blending of product water from one contactor (pH about 5.5) with high pH water from the neutralization cycle of a second contactor will decrease the time until the second contactor can be put on line, reduce chemical costs, and decrease the overall water requirements for neutralization. The volume of regeneration and neutralization water is generally 2-4% of the feed water volume.

Impact of Raw Water Quality on Treatment Cost

Raw water quality will have a major impact on the cost of fluoride removal. The principal factors are raw water pH, alkalinity and raw water fluoride concentration. Raw water pH is important because the activated alumina exchange capacity varies with pH, generally reaching its maximum exchange capacity at about pH 5.5. Operation at pH values higher or lower than pH 5.5 can substantially decrease the exchange capacity of activated alumina. However, an economic evaluation should be conducted to determine to what extent pH adjustment is justified in an effort to increase the alumina exchange capacity. Exchange capacities between 3.44 and 9.17 kg/m^3 (1,500 and 4,000 grains/cu ft) are typical, depending on raw water pH.

Raw water fluoride concentration also affects the regeneration frequency, with higher concentrations requiring more frequent regeneration.

Construction Costs

Costs presented are for systems which utilize the removal concepts presented previously. Contactors are steel, with rubber lining to prevent internal corrosion. A 1.5 m (5 ft) bed depth of activated alumina was used, with sufficient side depth of the contactors for 50% bed expansion during backwash. Contactors were located indoors. Although steel contactors were used in the cost estimate, fiberglass contactors would also be feasible for smaller sizes. Conceptual design criteria for the contactors is presented in Table 65 and a typical activated alumina installation is shown in Figure 54.

TABLE 65. CONCEPTUAL DESIGNS FOR ACTIVATED ALUMINA FLUORIDE REMOVAL

Plant Capacity, gpd	Number of Contactors	Diameter of Contactors, ft	Bed Depth, ft	Total Volume of Activated Alumina, cu ft	Housing, sq ft
45,000	2	2	5	32	100
102,000	2	3	5	71	180
180,000	2	4	5	126	228
406,000	2	6	5	283	252
552,000	2	7	5	385	375
722,000	2	8	5	502	625
1,082,000	3	8	5	754	875

Note: Sulfuric acid and sodium hydroxide storage tanks are not housed.

Storage of 66° B' sulfuric acid and 50% sodium hydroxide is in polyethelene storage tanks, located outdoors. Tanks are flat bottom mounted on a concrete slab. The sodium hydroxide tank includes an immersion heater to maintain the sodium hydroxide above its 14.4°C (58°F) freezing temperature. In extremely cold climates, indoor installation may be more economical and should be considered.

Day tanks are utilized for dilution, mixing, and storage of sulfuric acid and sodium hydroxide. Each day tank is equipped with a mixer. Sulfuric acid is metered to the feed line using a diaphragm pump, while sodium hydroxide feed is with two pumps, a small pump for product water neutralization during the treatment cycle, and a larger pump for the high sodium hydroxide flows required during regeneration.

Pipe and valve costs are based upon use of high temperature PVC pipe and fittings. Instrumentation costs include flow measurement and recording, pH sensors, and a high/low pH alarm.

Regenerant and backwash water can be expected to amount to 2-4% of the plant flow rate. Disposal may be to either a sanitary sewer or an evaporation pond. Depending upon regulatory agency requirements and proximity to usable groundwater aquifers, lining of ponds may be desirable and/or required. Costs are not included in the construction costs for regenerant or backwash water disposal.

Construction costs are presented in Table 66 and Figure 55.

TABLE 66. CONSTRUCTION COST SUMMARY FOR ACTIVATED ALUMINA FLUORIDE REMOVAL

Cost Category	Contactor Volume, cu ft						
	32	71	126	283	385	502	754
Excavation and Sitework	$ 4,700	$ 4,700	$ 4,700	$ 4,700	$ 4,700	$ 4,700	$ 4,700
Manufactured Equipment							
Equipment	12,800	23,900	39,100	50,600	64,500	72,900	101,000
Activated Alumina	1,400	3,100	5,400	11,900	15,400	19,600	29,400
Concrete	400	1,200	1,800	2,000	2,500	3,200	4,100
Labor, Installation	1,200	1,500	2,000	2,800	3,300	3,400	4,200
Pipe and Valves	5,200	6,500	6,500	8,400	12,800	13,300	20,100
Electrical, Instrumentation	6,400	6,400	6,400	8,000	8,000	8,500	9,600
Housing	8,700	14,400	16,900	17,900	24,800	34,400	43,900
Subtotal	40,800	61,700	82,800	106,300	136,000	160,000	217,000
Design Contingencies	6,100	9,300	12,400	15,900	20,400	24,000	32,600
Total	$46,900	$71,000	$95,200	$122,200	$156,400	$184,000	$249,600

Operation and Maintenance Requirements and Costs

The most important factor influencing operation and maintenance costs is the frequency of activated alumina regeneration. Frequent regeneration is necessary at low activated alumina exchange capacities, high raw water fluoride concentrations, or when low fluoride concentration product water is required. More frequent regeneration requires more labor, more chemicals, and higher activated alumina make-up requirements due to resin abrasion and loss during backwashing.

Process electrical energy is required for day tank mixers and diaphragm pumps to feed from the day tanks. Mixers were assumed to operate one-half hour per day, with the diaphragm feed pumps operating 24 hours per day. Feed water pumping costs are not included, nor are product water pumping costs. To maintain the 50% sodium hydroxide tank contents above the 14.4°C (58°F) freezing level, an electrical immersion heater was included for 4 hours per day and 180 days/year. In colder climates, designers should consider locating the sodium hydroxide storge tank indoors as this may lessen overall heating requirements.

Housing electrical energy is based upon an annual usage of 209 kwh/m^2/y (19.5 kwh/sq ft/yr), which includes lighting, ventiliation, and heating. Lighting is required only when the operator is present, which was assumed to average 3 hours per day.

Maintenance material costs are for activated alumina replacement, laboratory supplies, replacement pump diaphragms, and other miscellaneous parts. Activated alumina replacement was calculated on the basis of the number of backwashes/year, because backwashing results in abrasion of the activated alumina media, with a resultant loss as fines. A loss of 0.45% per backwash and an activated alumina cost of \$1,554/m^3 (\$44/cu ft) were used to calculate replacement costs.

Operational labor is required for preparation of chemical solutions used during treatment and regeneration, daily laboratory testing, and periodic regeneration of the alumina. One hour/day was used for chemical solution preparation, checking of the entire system, and laboratory testing. Labor requirements for regeneration are 4 hours/contactor/regeneration. In addition, maintenance labor is required for equipment repair, preventative maintenance, and periodic activated alumina replacement. Maintenance labor requirements utilized were 2 hours/day for the smaller contactors, ranging up to 5 hours/day for the largest contactor.

A summary of operation and maintenance costs for regeneration frequencies of 4.5, 8, 12, 19, 33, and 48 days is presented in Table 67 and in Figures 56 and 57.

Costs for the regenerant/backwash disposal are not included. These costs will vary depending upon whether evaporation ponds or a sanitary sewer are used for disposal, and must be added separately.

TABLE 67. OPERATION AND MAINTENANCE SUMMARY FOR ACTIVATED ALUMINA FLUORIDE REMOVAL

Average Plant Flow Rate, gpd	Activated Alumina Volume, cu ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Regeneration Frequency = 4.5 days							
45,000	31.4	2,000	4,400	6,400	900	1,280	15,400
101,000	70.7	3,500	9,500	13,000	1,600	1,280	16,600
180,000	126	4,500	16,600	21,100	2,500	1,332	18,600
406,000	283	4,900	18,300	23,200	5,100	1,332	21,400
553,000	385	7,300	18,300	25,600	6,800	1,384	23,800
722,000	503	12,200	18,300	30,500	8,700	1,384	26,100
1,083,000	754	17,100	18,300	35,400	12,700	1,842	35,400
Regeneration Frequency = 8 days							
45,000	31.4	2,000	4,400	6,400	700	914	11,200
101,000	70.7	3,500	9,500	13,000	1,100	914	12,100
180,000	126	4,500	16,600	21,100	1,600	966	13,700
406,000	283	4,900	18,300	23,200	3,000	966	15,300
553,000	385	7,300	18,300	25,600	4,000	1,018	17,000
722,000	503	12,200	18,300	30,500	5,000	1,018	18,400
1,083,000	754	17,100	18,300	35,400	7,300	1,293	24,000
Regeneration Frequency = 12 days							
45,000	31.4	2,000	4,400	6,400	600	776	9,600
101,000	70.7	3,500	9,500	13,000	900	776	10,400
180,000	126	4,500	16,600	21,100	1,300	828	11,900
406,000	283	4,900	18,300	23,200	2,200	828	13,000
553,000	385	7,300	18,300	25,600	2,900	880	14,400
722,000	503	12,200	18,300	30,500	3,700	880	15,500
1,083,000	754	17,100	18,300	35,400	5,200	1,085	19,600

TABLE 67 (Continued)

Average Plant Flow Rate, gpd	Activated Alumina Volume, cu ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Regeneration Frequency = 19 days							
45,000	31.4	2,000	4,400	6,400	500	660	8,200
101,000	70.7	3,500	9,500	13,000	700	660	8,900
180,000	126	4,500	16,600	21,100	1,000	712	10,300
406,000	283	4,900	18,300	23,200	1,600	712	11,100
Regeneration Frequency = 33 days							
553,000	385	7,300	18,300	25,600	2,000	764	12,200
722,000	503	12,200	18,300	30,500	2,500	764	13,100
1,083,000	754	17,100	18,300	35,400	3,500	912	16,000
45,000	31.4	2,000	4,400	6,400	500	580	7,300
101,000	70.7	3,500	9,500	13,000	600	580	7,900
180,000	126	4,500	16,600	21,100	800	632	9,200
406,000	283	4,900	18,300	23,200	1,100	632	9,700
553,000	385	7,300	18,300	25,600	1,400	684	10,700
722,000	503	12,200	18,300	30,500	1,700	684	11,400
1,083,000	754	17,100	18,300	35,400	2,300	792	13,500

TABLE 67 (Continued

Average Plant Flow Rate, gpd	Activated Alumina Volume, cu ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
		Building	Process	Total			
Regeneration Frequency = 48 days							
45,000	31.4	2,000	4,400	6,400	500	546	7,000
101,000	70.7	3,500	9,500	13,000	500	546	7,400
180,000	126	4,500	16,600	21,100	700	598	8,800
406,000	283	4,900	18,300	23,200	1,000	598	9,200
553,000	385	7,300	18,300	25,600	1,200	650	10,200
722,000	503	12,200	18,300	30,500	1,400	650	10,700
1,083,000	754	17,100	18,300	35,400	1,800	740	12,400

Notes: 1. Regeneration frequency = $\frac{\text{Exchange Capacity (Act. Alumina Volume)(17.1292)}}{\text{Average flow rate (Initial F - 2.0 mg/L)}}$

where: Exchange capacity = grains/cu ft
Activated alumina volume = cu ft
Average flow rate = gpd
17.1292 = constant
2.0 mg/L is the average product water fluoride concentration

2. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

Chemicals required are 66°B' sulfuric acid for pH adjustment prior to treatment and for neutralization after regeneration, and 50% sodium hydroxide for regeneration and for neutralization of product water after treatment. Chemical requirements vary with raw water pH and alkalinity, and overall chemical cost varies with dosage and cost per unit quantity of chemical. The best guidance for estimating typical requirements is from two full scale operations (Gila Bend and Palo Verde, Arizona) and results from pilot scale testing at North Myrtle Beach, South Carolina.[4,5] These costs are shown in Table 68.

Based upon Table 68, total chemical costs could reasonably be expected to fall within the range of \$0.0145 to 0.033/m^3 (\$55 to 125 dollars/million gal) treated for plants with capacities of over 1890 m^3/d (0.5 mgd), and for smaller plants such as Palo Verde, 45 m^3/d (11,900 gpd), up to \$0.145/m^3 (\$550/million gal) treated. Smaller plants are definitely impacted by loss of economy of scale in chemical purchases.

TABLE 68. TYPICAL CHEMICAL COSTS FOR ACTIVATED ALUMINA FLUORIDE REMOVAL

Location	Average Flow Rate, gpd	Chemical	Usage Rate	Unit Cost	$ / Million gal
Gila Bend, Arizona	473,000	H_2SO_4	15.8 gal/10^6 gal	\$ 40/ton	4.80
		NaOH	313 lb/10^6 gal	\$0.163/lb	51.00
					55.80
Palo Verde, Arizona	11,900	H_2SO_4	46.1 gal/10^6 gal	\$2.40/gal	110.70
		NaOH	460 lb/10^6 gal	\$0.52/lb	239.20
					349.90
N. Myrtle Beach, South Carolina	Pilot Plant	H_2SO_4	155.9 gal/10^6 gal	\$ 75/ton*	89.50
		NaOH	477 lb/10^6 gal	\$0.075/ton*	35.80
					125.30

*Chemical costs were based upon a proposed plant capacity of 2 mgd.

Note: For Gila Bend and North Myrtle Beach, sulfuric acid usage and costs are based on 66°B' with S.G. = 1.8354, and sodium hydroxide costs are based upon 50% NaOH with S.G. = 1.5253. For Palo Verde, Reference 5 did not give concentrations.

Field Data Collection

Field operating data were collected at Gila Bend, Arizona, which has a design capacity of 2,839 m^3/d (0.75 mgd) and an operating flow rate of 2,199 m^3/d (0.581 mgd). The total contactor volume is 21.3 m^3 (760 cu ft), and the average regeneration frequency is every 12 days.

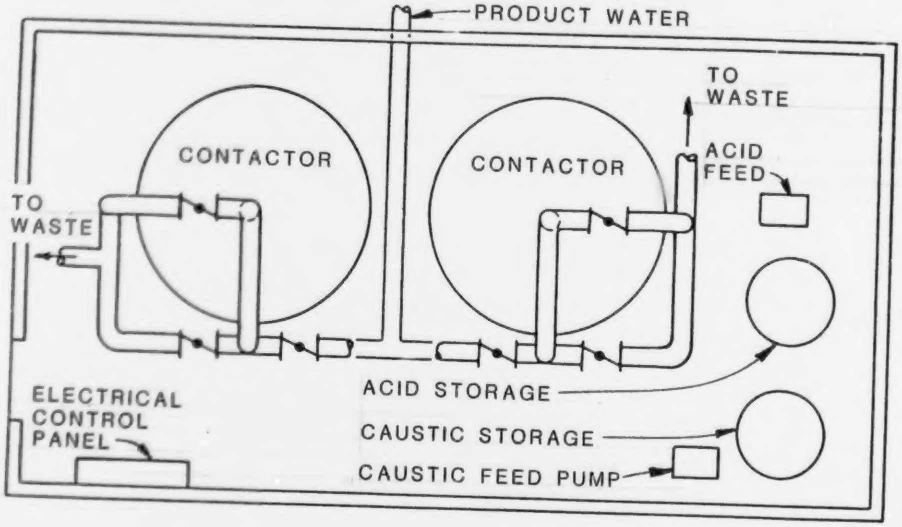
A comparison of field data and Figures 56 and 57 is as follows:

	Field Data	Data From Figures 56 and 57
Electrical Energy, kwh/hr		
Process	10,380	20,000
Building	1,650	18,000
Total	12,030	38,000
Maintenance Material, $/yr	2,180	5,000
Labor, hr/yr	828	1,000

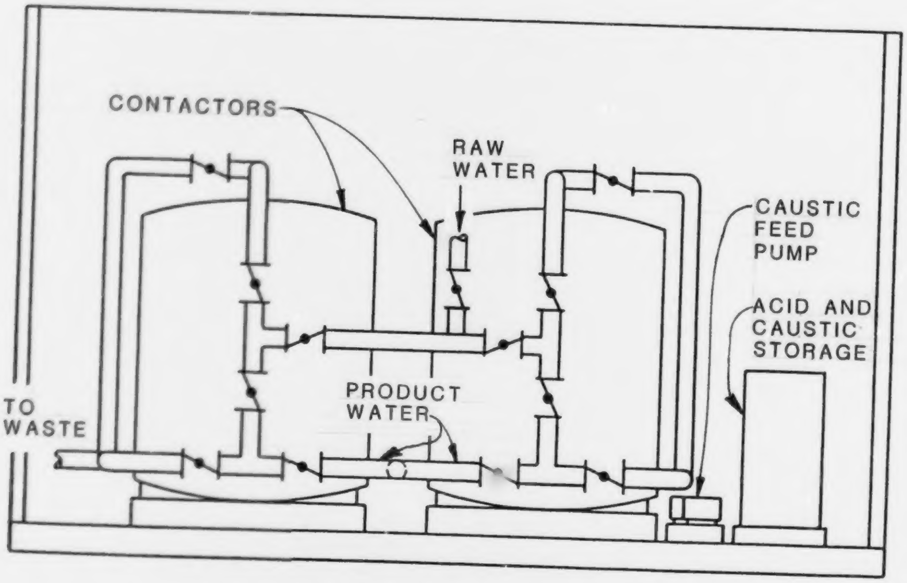
Field energy requirements, which are for heating the sodium hydroxide storage tank and for building heating, are lower than Figure 56 due to the mild climate in Gila Bend. Maintenance material is primarily for replacement of lost media. Field data are believed to be lower than Figure 56 because a lower percentage annual loss of activated alumina was experienced at Gila Bend. Labor requirements are comparable with Figure 57.

References

1. Rubel, F. and Woosley, "Removal of Excess Fluoride from Drinking Water," Technical Report EPA 570/9-78-001, January 1978.
2. Rubel, F. and Woosley, "The Removal of Excess Fluoride from Drinking Water by Activated Alumina," Journal AWWA, Volume 71, No. 1, January 1979, pp. 45-49.
3. Rubel, F., Personal Communication, 1982.
4. "Report on Development of Small Water System Treatment Costs for Removal of Excess Fluoride at Gila Bend, Arizona," Prepared by Rubel and Hager, Inc. as a portion of EPA Contract 68-03-3093, April 9, 1982.
5. "Interim Report, EPA/NSF Study of Defluoridation of Drinking Water In Small Communities," National Sanitation Foundation, EPA Contract R809248010, July 1982.


PRODUCT WATER
TO WASTE
CONTACTOR
CONTACTOR
ACID FEED
TO WASTE
ACID STORAGE
ELECTRICAL CONTROL PANEL
CAUSTIC STORAGE
CAUSTIC FEED PUMP

PLAN VIEW


CONTACTORS
RAW WATER
CAUSTIC FEED PUMP
ACID AND CAUSTIC STORAGE
PRODUCT WATER
TO WASTE

ELEVATION VIEW

Figure 54. Typical activated alumina fluoride removal installation.

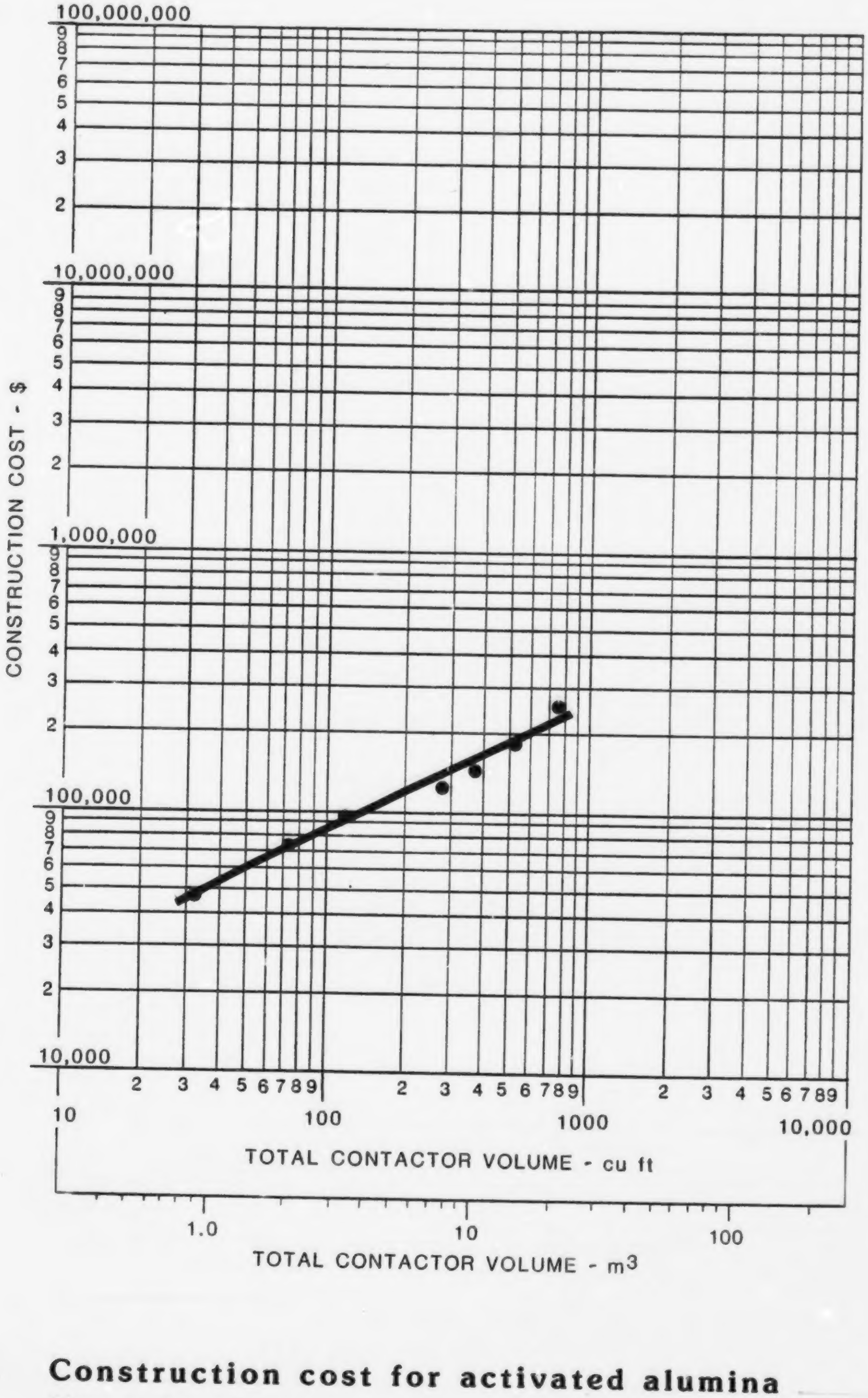


Figure 55. **Construction cost for activated alumina fluoride removal.**

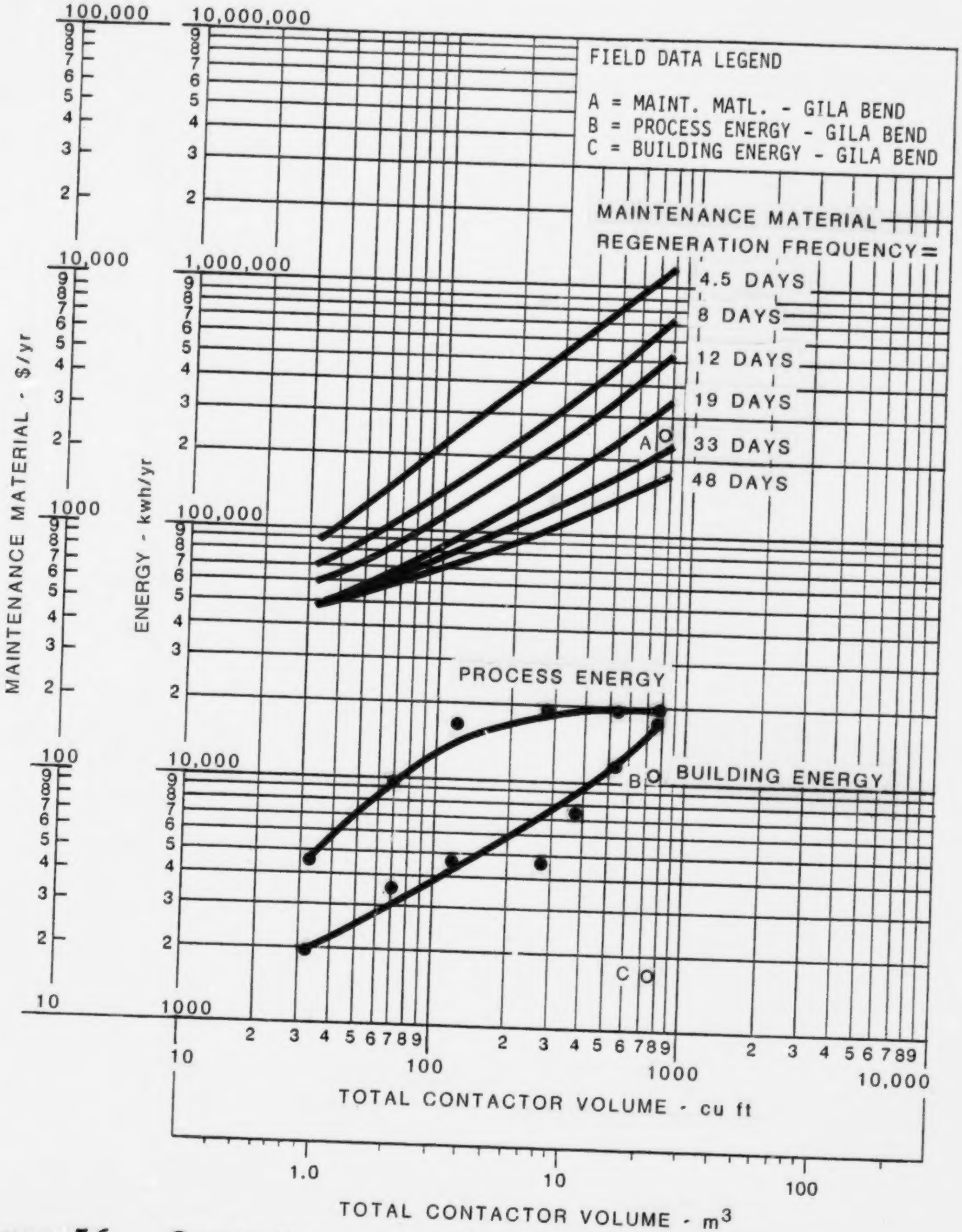


Figure 56. **Operation and maintenance requirements for activated alumina fluoride removal - building energy, process energy, and maintenance material.**

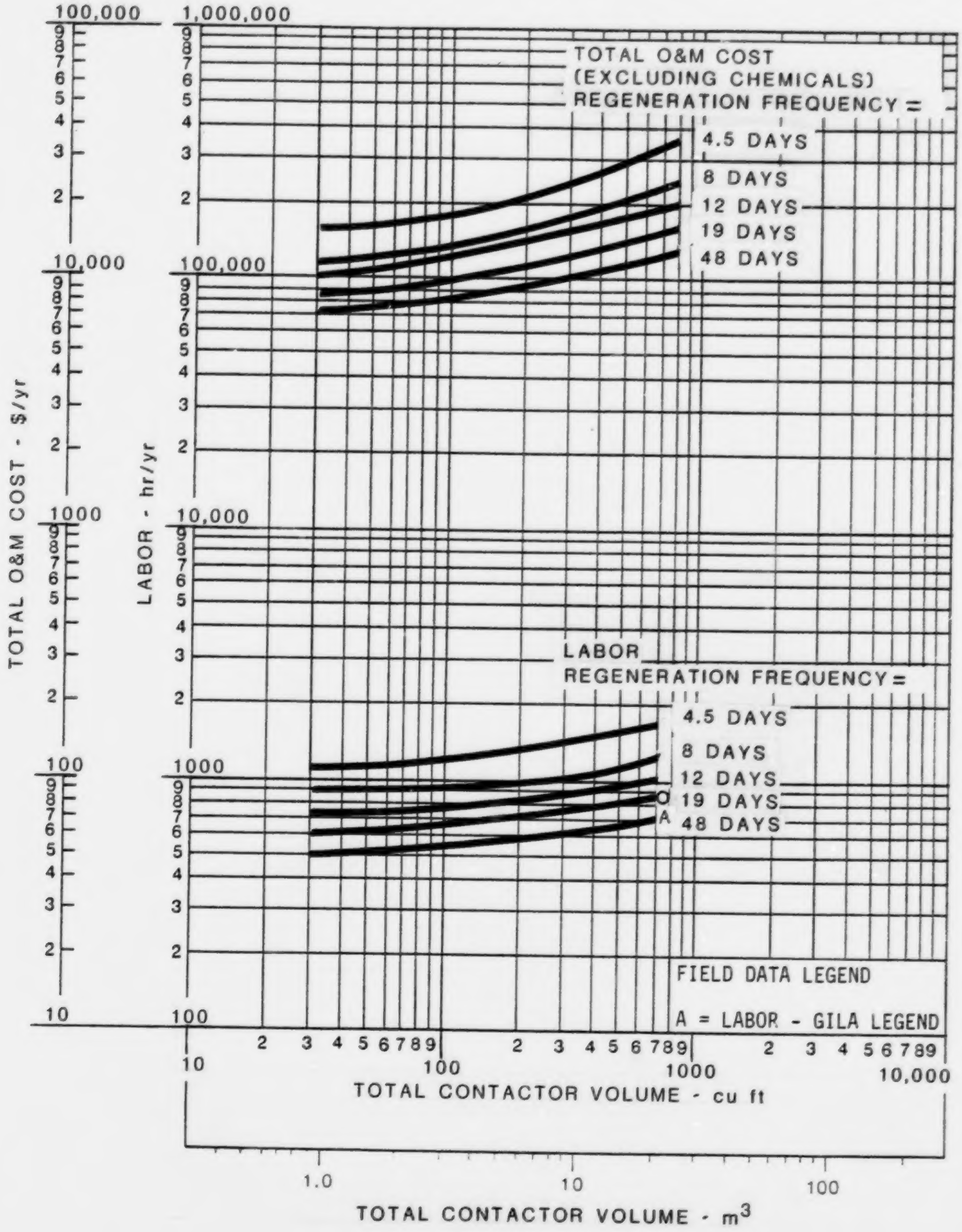


Figure 57. **Operation and maintenance requirements for activated alumina fluoride removal- labor and total O&M cost.**

GRANULAR ACTIVATED CARBON ADSORPTION

Introduction

Granular activated carbon removes organic contaminants from water by adsorption and in many cases can be used to remove organics which contribute to taste and odor problems, organics which are precursors in the trihalomethane formation reaction, and organics which may have adverse long-term health effects. In most existing applications, granular carbon serves a dual role by also performing as a filtration media for removal of suspended material from the water being treated. In small applications the granular carbon is generally contained in pressurized downflow or upflow contactors designed with internal piping to distribute influent over the carbon bed and uniformly collect the treated water. Gravity downflow operation is also possible using open top tanks. The following sections present costs for each of these treatment configurations.

Flow rates generally vary from 6.2 to 12.2 $m^3/m^2/h$ (2.5 to 5 gpm/sq ft) and bed depths are normally 0.76 to 3.05 m (2.5 to 10 ft). Contact time is the governing criteria affecting carbon performance. Generally, an empty bed contact time (EBCT) of 5 to 15 minutes provides optimum adsorption of organics commonly found in water supplies. However, pilot scale testing is generally conducted before an EBCT is selected.

Impact of Raw Water Quality on Treatment Cost

The treatment cost associated with the use of granular activated carbon is affected directly by the concentration of adsorbable organics in the water being treated. First, initial cost can increase as organic concentrations increase, because a longer EBCT may be required. A longer EBCT will require a larger contactor volume, with a resultant increase in capital cost. Secondly, as the organic concentration increases, the carbon is exhausted more rapidly. This requires more frequent reactivation, with a resultant increase in operation and maintenance costs.

PACKAGE PRESSURE GRANULAR ACTIVATED CARBON CONTACTORS

Construction Costs

Costs presented are for factory assembled units which are mounted on a steel skid. Conceptual design data for carbon contactors and equipment housing are presented in Table 69. Carbon contactors are cylindrical steel, downflow contactors conforming to the ASME code for pressure vessels designed for a working pressure of 3.52 kg/cm^2 (50 psi). The contactors, which have an overall height of 3.66 m (12 ft) and are internally coated to resist corrosion, are designed for a five foot carbon bed depth with varying diameters. The tanks are furnished with inlet and outlet connections, a nozzle-style underdrain, access opening for filling and removing carbon, manual ball or butterfly valves, differential pressure gauge and an initial charge of activated carbon. A supply and backwash pump are skid-mounted with the carbon contactor. A typical installation is shown in Figure 58. The costs include face piping and supply piping. Also included are costs for equipment housing, but costs are not included for raw or finished water pumping or carbon handling or conveyance systems. Construction costs are presented in Table 70 and Figure 59 for systems with carbon volumes ranging between 0.049 and 22 m^3 (1.75 and 785 cu ft).

Operation and Maintenance Requirements and Costs

Operation and maintenance costs were developed from the conceptual designs presented in Table 71. It was assumed that the carbon columns function as adsorption units, and when filtration is necessary, that it preceeds the carbon contactors.

TABLE 71. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE PRESSURE GRANULAR ACTIVATED CARBON CONTACTORS

Contactor Volume, cu ft	Energy, kwh/yr Building	Energy, kwh/yr Process	Energy, kwh/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
1.75	2,000	10	2,010	100	190	2,300
15.7	3,100	10	3,110	250	220	2,900
63	4,700	20	4,720	650	290	4,200
141	6,600	50	6,650	750	340	5,000
251	9,900	80	9,980	950	380	5,800
393	12,900	120	13,020	1,300	420	6,800
785	16,300	250	16,550	2,000	560	9,300

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Process energy requirements are for backwash pumping, and assume one backwash per week for 20 minutes at a rate of 24.4 m^3/m^2/h (10 gpm/sq ft) and

TABLE 69. CONCEPTUAL DESIGNS FOR PACKAGE PRESSURE GRANULAR ACTIVATED CARBON CONTACTORS

Volume, cu ft	Carbon Contactors			Housing		Treatment Capacity, gpd		
	Bed Depth, ft	Diameter, ft	Number	Dimensions LxWxH, ft	Area, sq ft	EBCT = 5 Min	EBCT = 10 min	EBCT = 15 min
1.75	5	0.67	1	10 x 10 x 14	100	3,770	1,880	1,260
15.7	5	2	1	16 x 10 x 14	160	33,800	16,900	11,300
63	5	4	1	20 x 12 x 14	240	135,700	67,900	45,200
141	5	6	1	24 x 14 x 14	336	303,700	151,900	101,200
251	5	8	1	28 x 18 x 14	504	540,700	270,400	180,200
393	5	10	1	30 x 22 x 14	660	846,600	423,300	282,200
785	5	10	2	32 x 26 x 14	832	1,691,100	845,500	563,700

Note: Treatment capacity in gallons/day is calculated according to the formula:

$$\frac{\text{contactor volume in cu ft (10,771)}}{\text{EBCT in minutes}}$$

TABLE 70. CONSTRUCTION COST SUMMARY FOR PACKAGE PRESSURE GRANULAR ACTIVATED CARBON CONTACTORS

Cost Category	Carbon Contactor Volume, cu ft						
	1.75	15.7	63	141	251	393	785
Excavation and Sitework	$ 1,200	$ 1,600	$ 2,400	$ 3,400	$ 5,000	$ 5,900	$ 7,000
Manufactured Equipment	4,100	15,100	34,000	42,600	52,900	64,400	128,800
Concrete	1,700	2,600	3,900	5,400	8,000	10,200	12,900
Labor, Installation	1,200	4,500	10,200	12,800	15,900	19,300	29,000
Pipe and Valves	400	1,500	3,400	4,300	5,300	6,400	11,200
Electrical, Instrumentation	2,100	5,000	9,800	12,600	16,500	20,300	30,500
Housing	8,800	13,100	18,000	22,500	29,700	34,300	39,100
Subtotal	19,500	43,400	81,700	103,600	133,300	160,800	258,500
Design Contingencies	2,900	6,500	12,300	15,500	20,000	24,100	38,800
Total	$22,400	$49,900	$94,000	$119,100	$153,300	$184,900	$297,300

a TDH of 9.14 m (30 ft). Supply pumping and product water pumping are not included. Building energy requirements are for heating, lighting, and ventilation of the structures. Lighting was assumed to be three hours per day.

Maintenance material requirements were estimated from anticipated costs of replacement parts and replenishment of consumable supplies involved in the daily operation of the equipment. These items include lubricants, pump parts, instrumentation repair and general facility maintenance. The cost of replacement carbon, which is a major operating expense, is not included in the maintenance material costs. Typical costs for replacement carbon are presented in the following section.

Labor requirements were developed assuming that the facilities operate essentially unattended. Labor requirements involve backwashing the carbon column once per week, performing routine maintenance tasks (such as pump lubrication and occasional replacement of pump seals), and monitoring the performance of the carbon contactors. No allowance for administrative or for laboratory labor, other than for minimal routine water quality testing, is included.

Operation and maintenance requirements are summarized in Table 71 and are shown in Figures 60 and 61.

Typical Chemical Requirements and Costs

The concentration of adsorbable organics in the water supply as well as their adsorption characteristics establishes the carbon requirements for a granular activated carbon contacting system. Typically, for taste and odor reduction, the carbon requirement will range between 2 and 10 mg/L (0.0034 and 0.0172 lb/1,000 gal). For removal of trihalomethane (THM) forming organics, required carbon dosages may be as much as an order of magnitude greater. Values of 0.0227 to 0.1135 kg organics removed per kg (0.0227 to 0.1135 lb/lb) of carbon have been observed where carbon has been used for THM precursor removal.

The carbon requirement is a function of the EBCT and the frequency of carbon replacement. Carbon requirement in pounds/1,000 gallons treated is calculated using the following two formulas:

1st Formula

$$\text{lb carbon used} = (\text{cu ft of carbon})(26\ \text{lb/cu ft})$$

2nd Formula

Flow treated prior to carbon replacement =

$$= \frac{\text{cu ft of carbon }(7.48\ \text{gal/cu ft})(525{,}600\ \text{min/yr})(\text{frequency of replacement})}{\text{EBCT }(12\ \text{mo/yr})}$$

$$= \frac{\text{cu ft of carbon }(\text{frequency of replacement})(327{,}624)}{\text{EBCT}}$$

where:

EBCT = minutes
frequency of replacement = months

Combining these two formulas, yields a formula for the carbon requirement:

$$\text{lb carbon/1,000 gallons} = \frac{(\text{cu ft of carbon})(26\ \text{lb/cu ft})(\text{EBCT})(1{,}000)}{(\text{cu ft of carbon})(\text{frequency of replacement})(327{,}624)}$$

$$= \frac{\text{EBCT}}{(\text{frequency of replacement})(12.6)}$$

The annual cost for carbon replacement is a function of the contactor volume and the frequency of carbon replacement. Table 72 presents annual carbon costs for replacement frequencies of 3, 6, 9, and 12 months. These costs are based upon an installed carbon cost of \$2.64/kg (\$1.20/lb). For other replacement frequencies, the formula presented at the bottom of Table 72 can be used.

TABLE 72. ANNUAL COST FOR CARBON REPLACEMENT

Contactor Volume, cu ft	Frequency of Carbon Replacement			
	3 months	6 months	9 months	12 months
1.75	$ 220/yr	$ 110/yr	$ 75/yr	$ 60/yr
15.7	2,000	1,000	650	490
63	7,900	3,900	2,600	2,000
141	17,600	8,800	5,850	4,400
251	31,300	15,700	10,400	7,800
393	49,100	24,500	16,300	12,300
785	98,000	49,000	32,600	24,500

Notes: 1. Carbon density = 26 lb/cu ft.
Carbon cost (installed) is \$1.20/lb.
3. For calculation of annual cost at other replacement frequencies, use the following formula:

$$\$/\text{yr} = \frac{(\text{cu ft of Carbon})(26\ \text{lb/cu ft})(\$1.20/\text{lb})(12\ \text{mo/yr})}{(\text{Carbon Replacement Frequency in Months})}$$

Field Data Collection

Pressure granular activated carbon treatment operating data were collected at Rockaway Township, New Jersey, and the Borough of Rockaway, New Jersey. The total GAC contactor volumes at these utilities were 44.5 m^3 (1,570 cu ft) and 66.7 m^3 (2,355 cu ft), respectively.

A comparison of field operating data and data from Figures 60 and 61 is shown following:

	Rockaway Township		Borough of Rockaway	
	Field Data	Data From Figures 60 and 61	Field Data	Data From Figures 60 and 61
Electrical Energy, kwh/hr				
Process	-	400	-	600
Building	-	23,000	-	28,000
Total	37,800	23,400	149,650	28,600
Maintenance Material, $/yr	-	3,000	980	3,900
Labor, hr/yr	780	650	271	700

At both utilities, field data electrical/energy is significantly greater than energy requirements shown in Figure 60, because product water pumping is included in the field data. No maintenance material data are available for Rockaway Township. The low labor requirement at Borough of Rockaway may be due to the allocation of labor between carbon treatment and the packed tower air stripping unit.

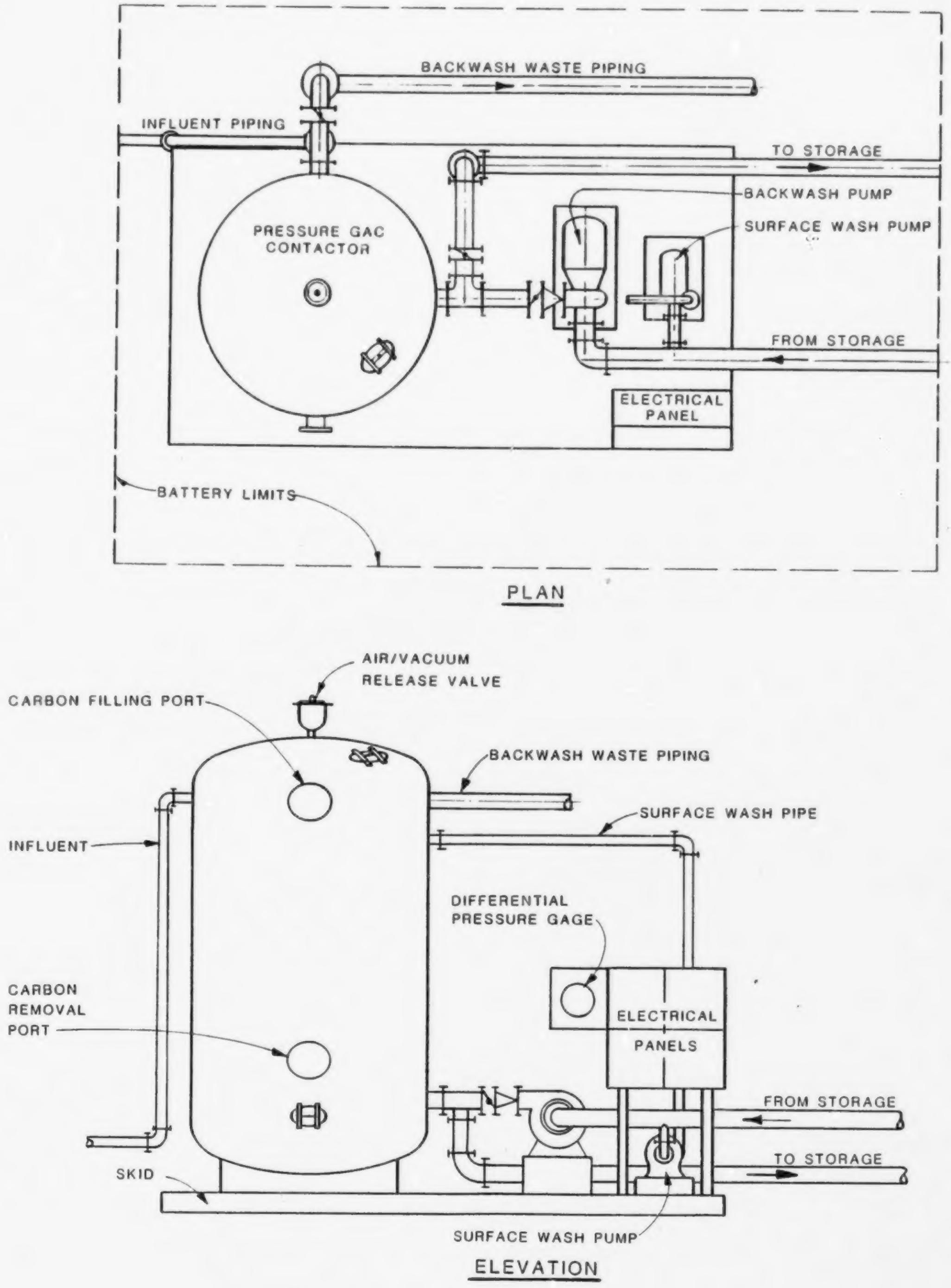

BACKWASH WASTE PIPING
INFLUENT PIPING
TO STORAGE
BACKWASH PUMP
SURFACE WASH PUMP
PRESSURE GAC CONTACTOR
FROM STORAGE
ELECTRICAL PANEL
BATTERY LIMITS
PLAN
AIR/VACUUM RELEASE VALVE
CARBON FILLING PORT
BACKWASH WASTE PIPING
SURFACE WASH PIPE
INFLUENT
DIFFERENTIAL PRESSURE GAGE
CARBON REMOVAL PORT
ELECTRICAL PANELS
FROM STORAGE
TO STORAGE
SKID
SURFACE WASH PUMP
ELEVATION

Figure 58. Typical skid-mounted GAC contactor installation

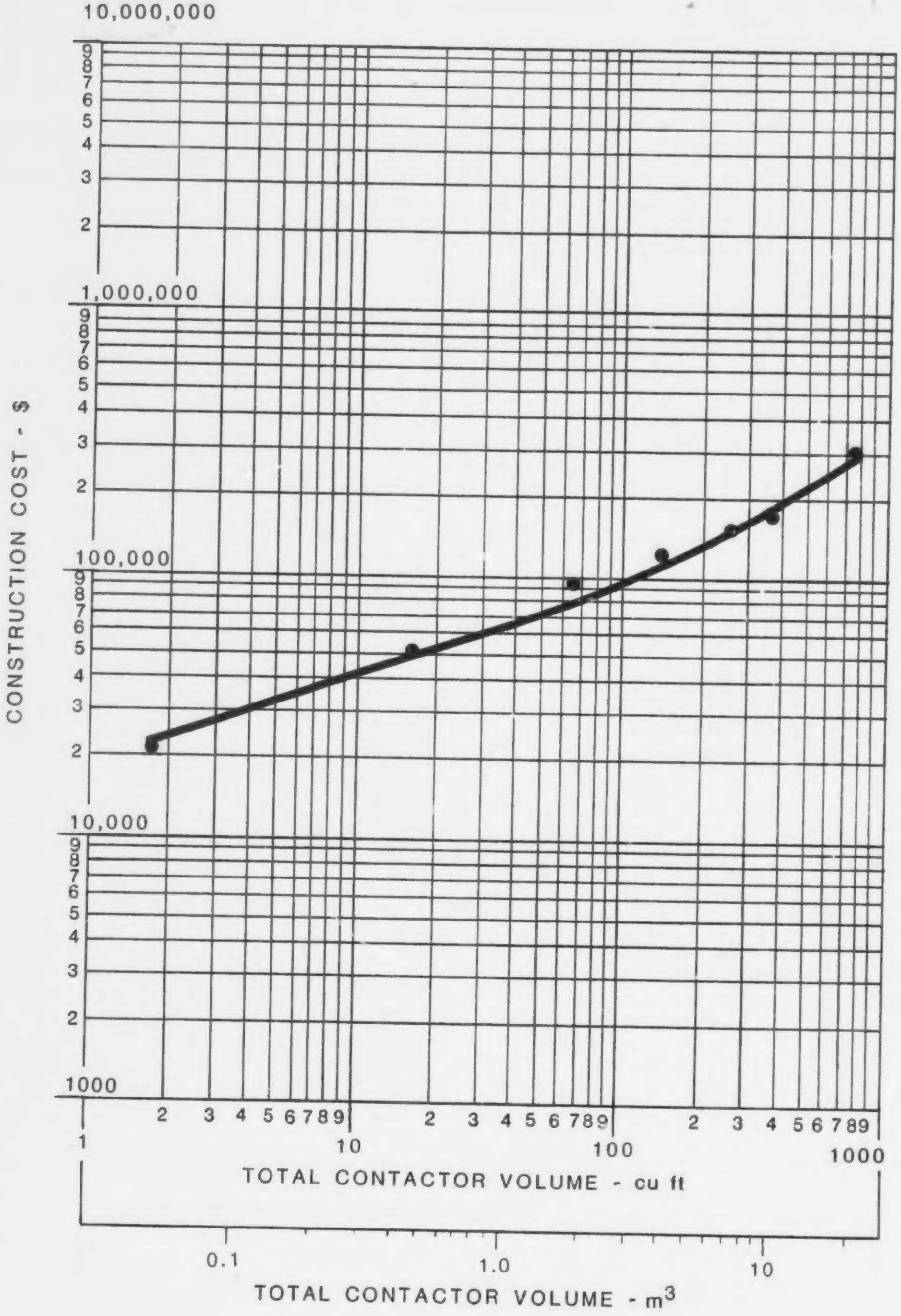


Figure 59. **Construction cost for package pressure granular activated carbon contactors.**

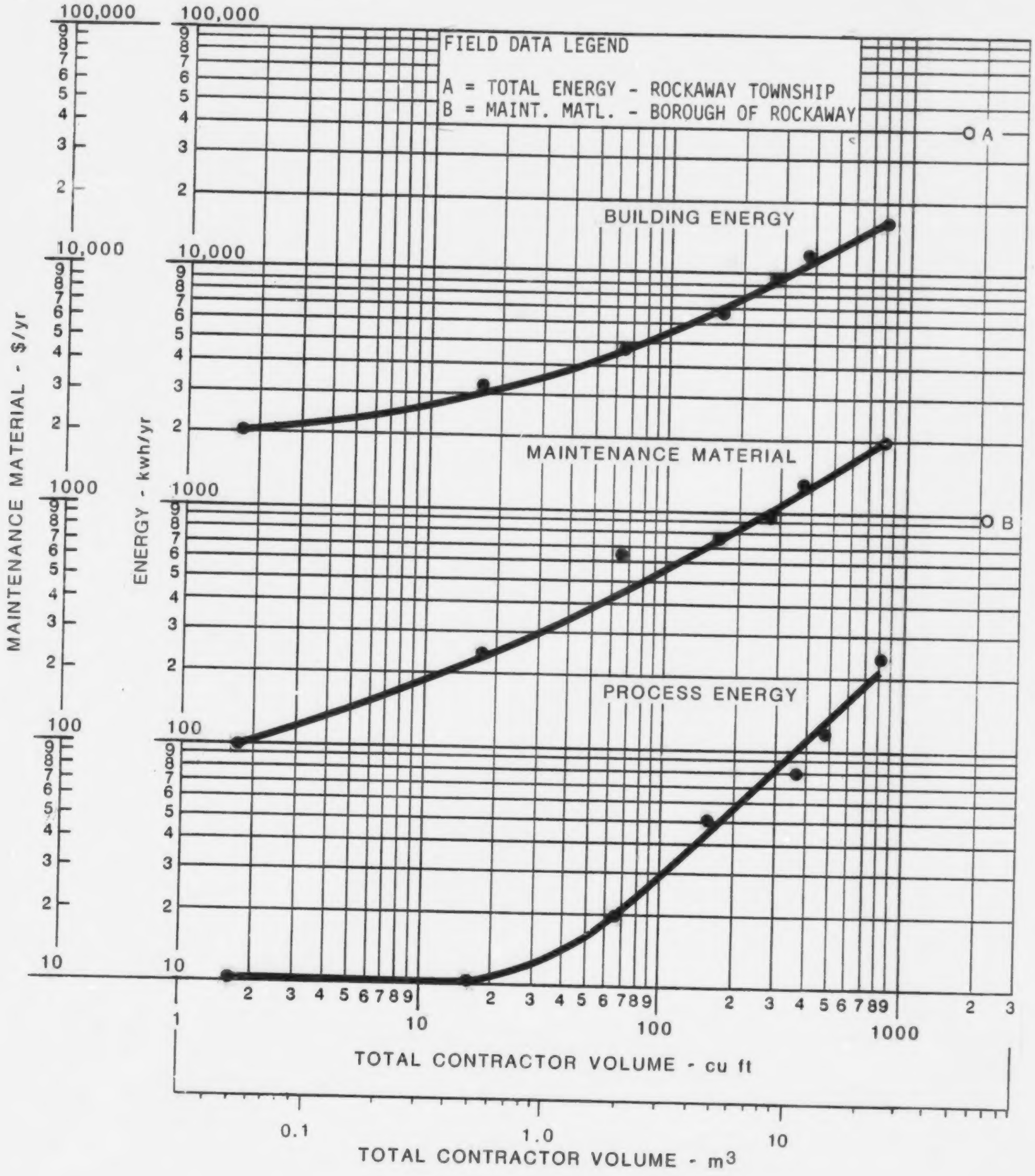


Figure 60. **Operation and maintenance requirements for package pressure granular activated carbon contactors - building energy, process energy and maintenance material.**

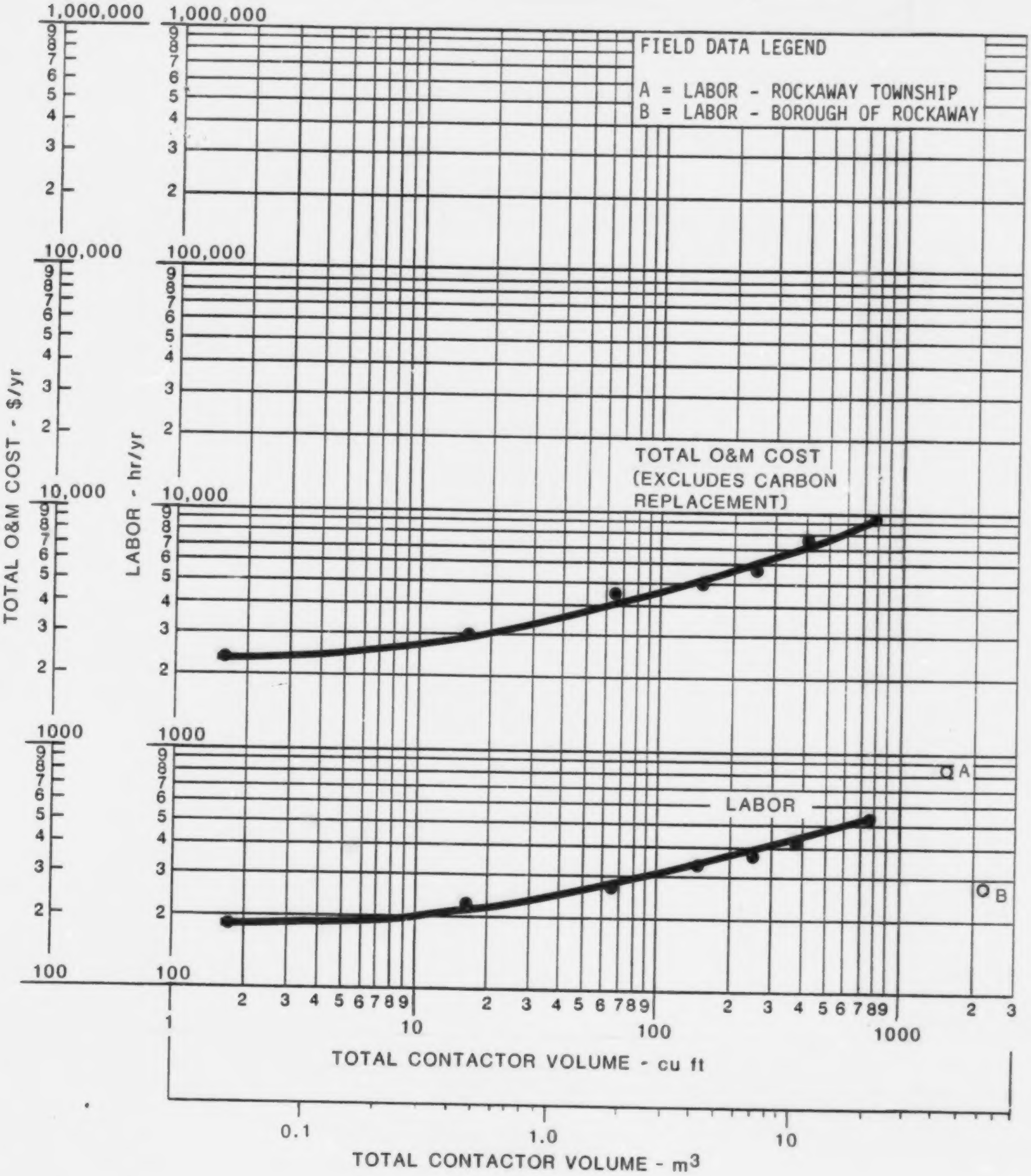


Figure 61. **Operation and maintenance requirements for package pressure granular activated carbon contactors - labor and total O&M costs.**

PACKAGE GRAVITY GRANULAR ACTIVATED CARBON CONTACTORS

Construction Costs

Construction costs were developed for package gravity GAC plants with carbon volumes ranging between 0.88 and 31.64 m^3 (31.5 and 1,130 cu ft). Each plant consists of two contactors, arranged similarily to the typical layout shown in Figure 62. Conceptual designs for various total contactor volumes are shown in Table 73.

The carbon contactors are cylindrical, open-top tanks with a 3.66 m (12 ft) side shell height and are fabricated of 0.64 and 0.79 cm (1/4 and 5/16 in) thick, mild steel plate. The tanks are painted on the inside and outside to prevent corrosion. Within the tank, the carbon bed is supported on a layer of graded gravel which is placed over a pipe lateral underdrain. A single wash trough is used on each of the contactors.

In addition to piping connections for influent and effluent, the tanks include nozzles for introducing replacement carbon and removal of spent carbon. These nozzles have manual butterfly valves. Automatic, air-operated butterfly valves are provided for influent, backwash waste, effluent rate of flow control and backwash supply. The valves are controlled by an automatic backwash programmer, which is manually initiated by the plant operator.

The construction costs presented in Figure 63 and Table 74 include a supply pump, backwash pump, face piping, and an initial charge of activated carbon and housing. Costs for a clearwell and product water pumping are not included in the construction costs.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements were developed assuming the carbon contactors function as adsorption units and are preceded by filtration where needed.

Process energy is required for backwash pumping. Backwash pump energy consumption is based upon one backwash per week for each contactor, 20 minutes per backwash, TDH = 9.14 m (30 ft), and a backwash rate equal to 24.4 $m^3/m^2/h$ (10 gpm/sq ft). Building energy requirements are for heating, lighting, and ventilation of the structures, and assume lighting requirements are three hours per day.

Maintenance material requirements were estimated from anticipated costs of replacement parts and replenishment of consumable supplies involved in the daily operation of the equipment. The cost of replacement carbon, which is a major operating expense, is not included in the maintenance material costs. Costs for replacement carbon at several different replacement frequencies are discussed in the following section.

Labor requirements were developed assuming that the facilities operate essentially unattended. Labor requirements involve initiating the automatic backwash cycle once per week and overseeing the backwash cycle operation,

TABLE 73. CONCEPTUAL DESIGNS FOR PACKAGE GRAVITY GRANULAR ACTIVATED CARBON CONTACTORS

	Carbon Contactors				Housing		Treatment Capacity, gpd		
Volume, cu ft	Bed Depth, ft	Diameter, ft	Total Bed Area, sq ft	Number	Dimensions LxWxH, ft	Area, sq ft	EBCT = 5 min	EBCT = 10 min	EBCT = 15 min
31.5	5	2	6.3	2	14x13x14	182	67,900	33,900	22,600
125	5	4	25	2	20x18x14	360	269,300	134,600	89,800
285	5	6	57	2	24x20x14	480	613,900	307,000	204,600
500	5	8	100	2	30x24x14	720	1,077,100	538,600	359,000
790	5	10	156	2	40x28x14	1,120	1,701,800	850,900	567,300
1,130	5	12	226	2	46x30x14	1,380	2,434,200	1,217,100	811,400

Notes:
1. Volume shown is the total volume of both contactors.
2. Treatment capacity in gallons/day is calculated according to the formula:

$$\frac{\text{contactor volume in cu ft (10,771)}}{\text{EBCT im minutes}}$$

TABLE 74. CONSTRUCTION COST SUMMARY FOR PACKAGE GRAVITY GRANULAR ACTIVATED CARBON CONTACTORS

Cost Category	Carbon Contractor Volume, cu ft					
	31.5	125	285	500	790	1,130
Excavation and Sitework	$ 1,800	$ 3,600	$ 4,800	$ 6,500	$ 9,000	$ 11,000
Manufactured Equipment	9,800	18,600	30,200	52,100	80,800	106,700
Concrete	2,900	5,400	7,200	10,000	15,700	18,000
Labor, Installation	3,000	5,600	7,700	13,300	20,600	26,700
Pipe and Valves	4,800	8,500	12,000	16,000	24,500	33,000
Electrical, Instrumentation	4,600	8,700	11,900	18,400	28,300	36,000
Housing	14,600	24,500	28,800	37,400	47,000	51,100
Subtotal	41,500	74,900	102,600	153,700	225,900	282,500
Design Contingencies	6,200	11,200	15,400	23,100	33,900	42,400
Total	$47,700	$86,100	$118,000	$176,800	$259,800	$324,900

performing routine maintenance tasks (such as pump lubrication and occasional replacement of pump seals), and monitoring the performance of the carbon contactors. No allowance for administrative or for laboratory labor, other than for minimal routine water quality testing conducted by the plant operator for operational control purposes, is included.

Operation and maintenance requirements are summarized in Table 75 and are shown in Figures 64 and 65.

Typical Chemical Requirements and Costs

The annual cost for carbon replacement is a function of the carbon contactor volume and the frequency of carbon replacement. Installed carbon costs are shown in Table 76 for carbon replacement frequencies of 3, 6, 9, and 12 months. A formula is presented at the bottom of Table 76 for the installed carbon cost at other replacement frequencies.

TABLE 76. ANNUAL COST FOR CARBON REPLACEMENT

Contactor Volume, cu ft	Frequency of Carbon Replacement			
	3 months	6 months	9 months	12 months
31.5	$ 3,930/yr	$ 1,970/yr	$ 1,310/yr	$ 980/yr
125	15,600	7,800	5,200	3,900
285	35,600	17,800	11,900	8,900
500	62,400	312,000	20,800	15,600
790	98,600	49,300	32,900	24,600
1,130	141,000	70,500	47,000	35,300

Notes:
1. Carbon density = 26 lb/cu ft.
2. Carbon cost (installed) is $1.20/lb.
3. For calculation of annual cost at other replacement frequencies, use the following formula:

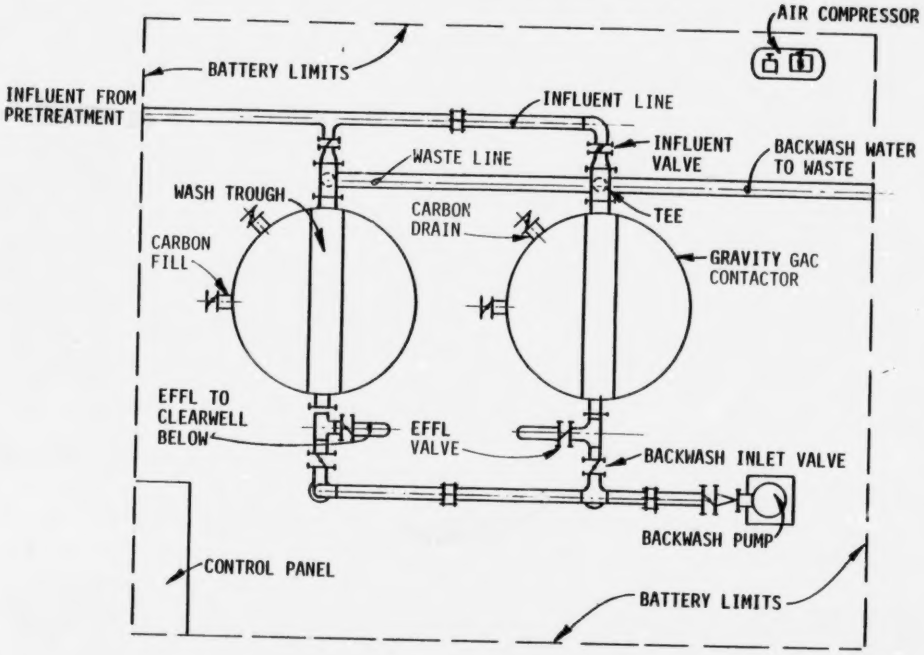
$$\$/\text{yr} = \frac{(\text{cu ft of Carbon})(26\ \text{lb/cu ft})(\$1.20/\text{lb})(12\ \text{mo/yr})}{(\text{Carbon Replacement Frequency in Months})}$$

Carbon requirements, which are a function of the frequency of carbon replacement and EBCT, can be calculated using the formula presented in the prior section titled "Package Pressure Granular Activated Carbon Columns."

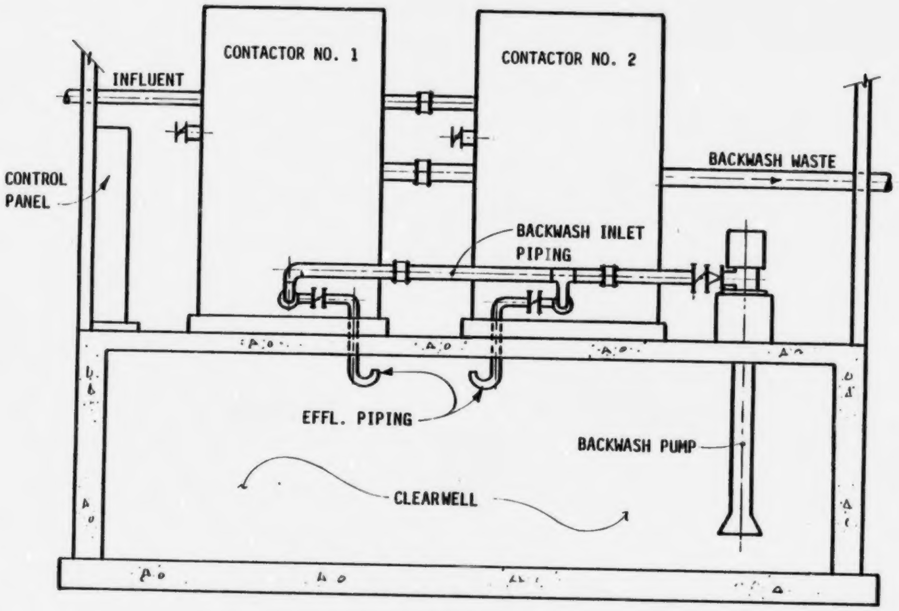
TABLE 75. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE GRAVITY GRANULAR ACTIVATED CARBON CONTACTORS

Volume, cu ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
31.5	3,600	10	3,610	600	300	4,200
125	7,000	40	7,040	1,100	400	6,000
285	9,400	90	9,490	1,200	470	7,000
500	14,100	160	[illegible]	1,500	510	8,100
790	21,900	250	22,150	2,300	550	9,900
1,130	26,900	350	27,250	2,800	610	11,400

Notes:
1. Maintenance materials and labor cost do not include carbon removal and replacement.
2. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.


AIR COMPRESSOR
BATTERY LIMITS
INFLUENT FROM PRETREATMENT
INFLUENT LINE
INFLUENT VALVE
BACKWASH WATER TO WASTE
WASTE LINE
WASH TROUGH
CARBON DRAIN
TEE
CARBON FILL
GRAVITY GAC CONTACTOR
EFFL TO CLEARWELL BELOW
EFFL VALVE
BACKWASH INLET VALVE
BACKWASH PUMP
CONTROL PANEL
BATTERY LIMITS

PLAN


CONTACTOR NO. 1
CONTACTOR NO. 2
INFLUENT
CONTROL PANEL
BACKWASH WASTE
BACKWASH INLET PIPING
EFFL. PIPING
BACKWASH PUMP
CLEARWELL

ELEVATION

TYPICAL GRAVITY GAC COLUMNS

Figure 62. Typical package gravity GAC contactor installation.

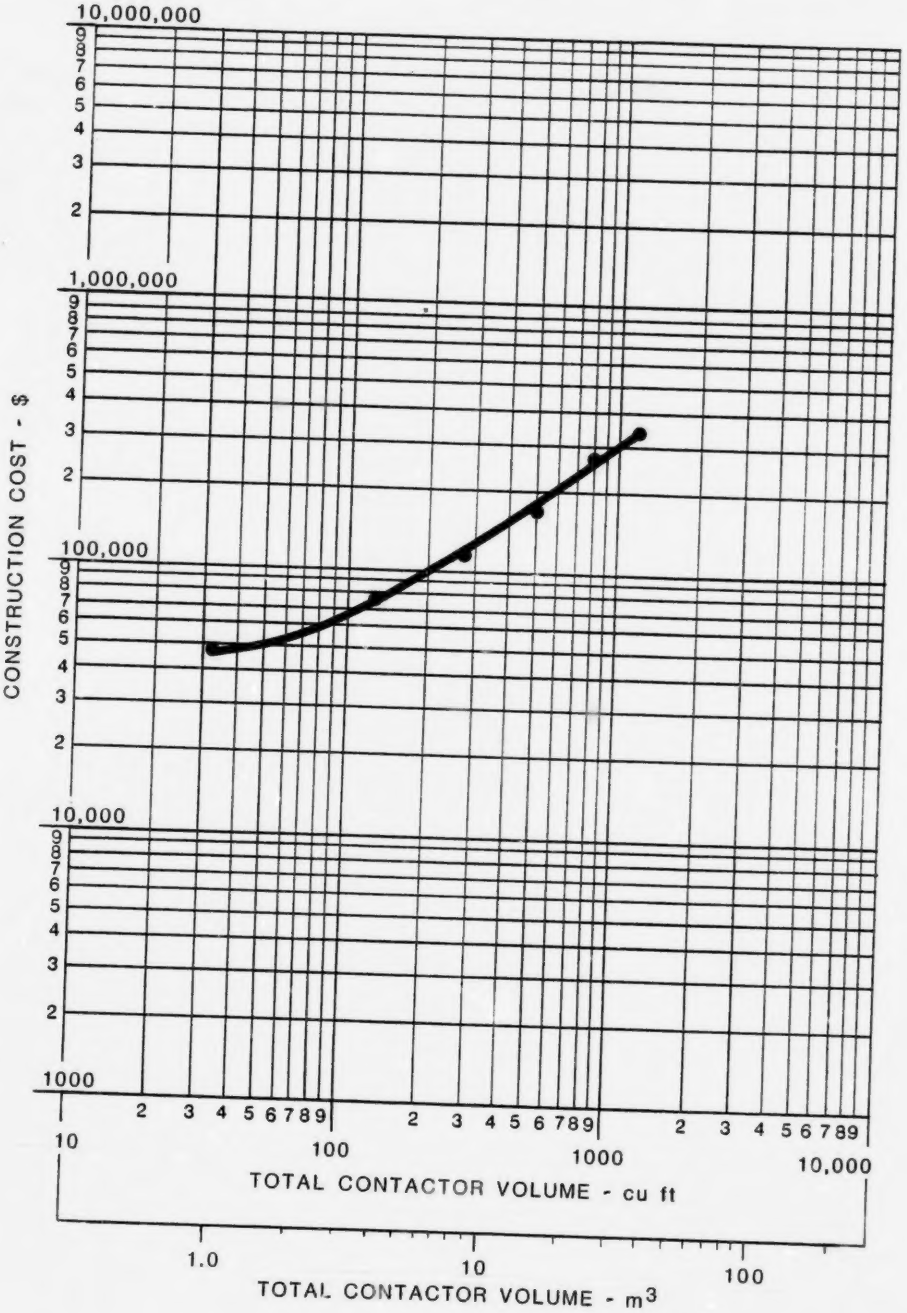


Figure 63. **Construction cost for package gravity granular activated carbon contactors.**

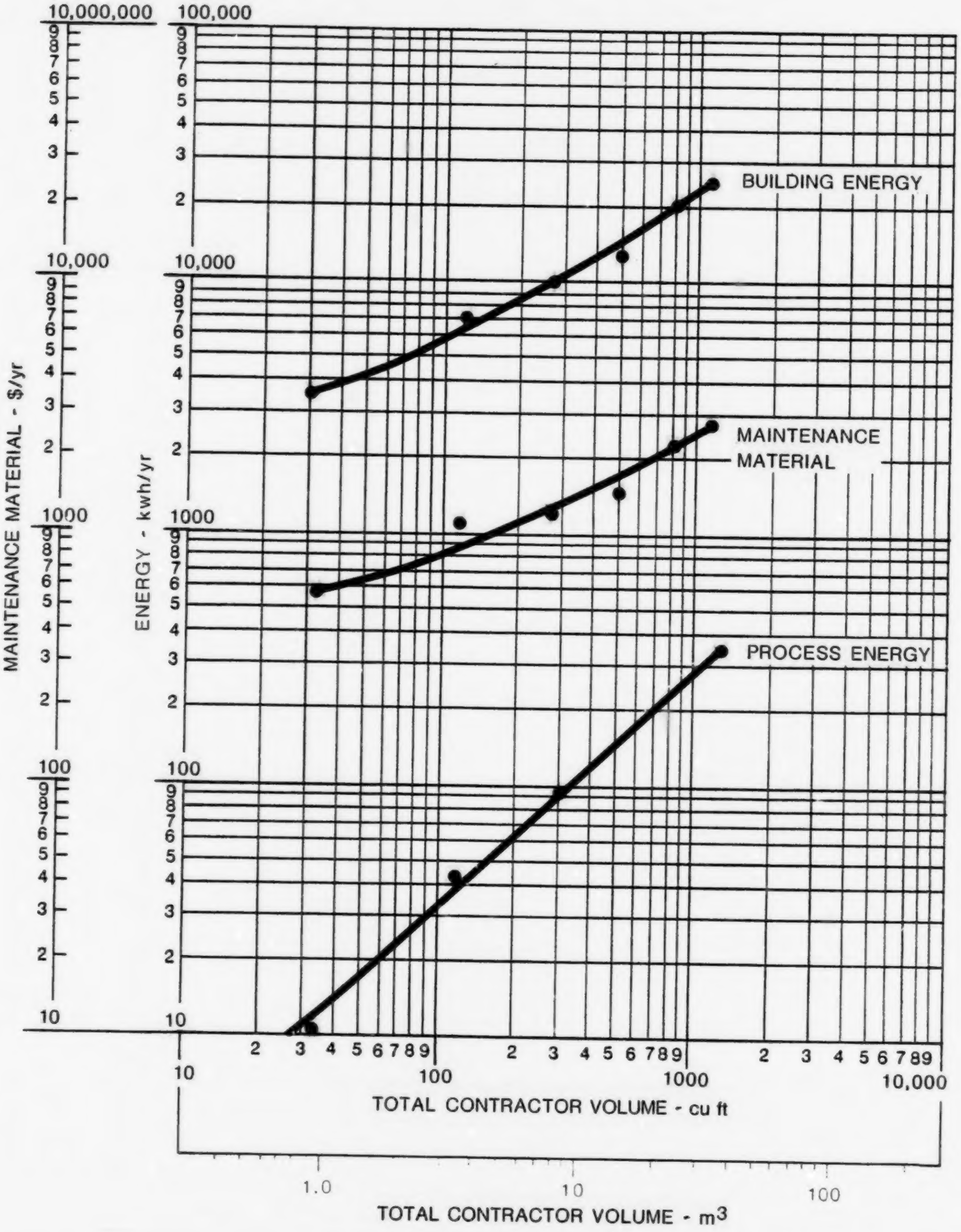


Figure 64. Operation and maintenance requirements for package gravity granular activated carbon contactors - building energy, process energy, and maintenance material.

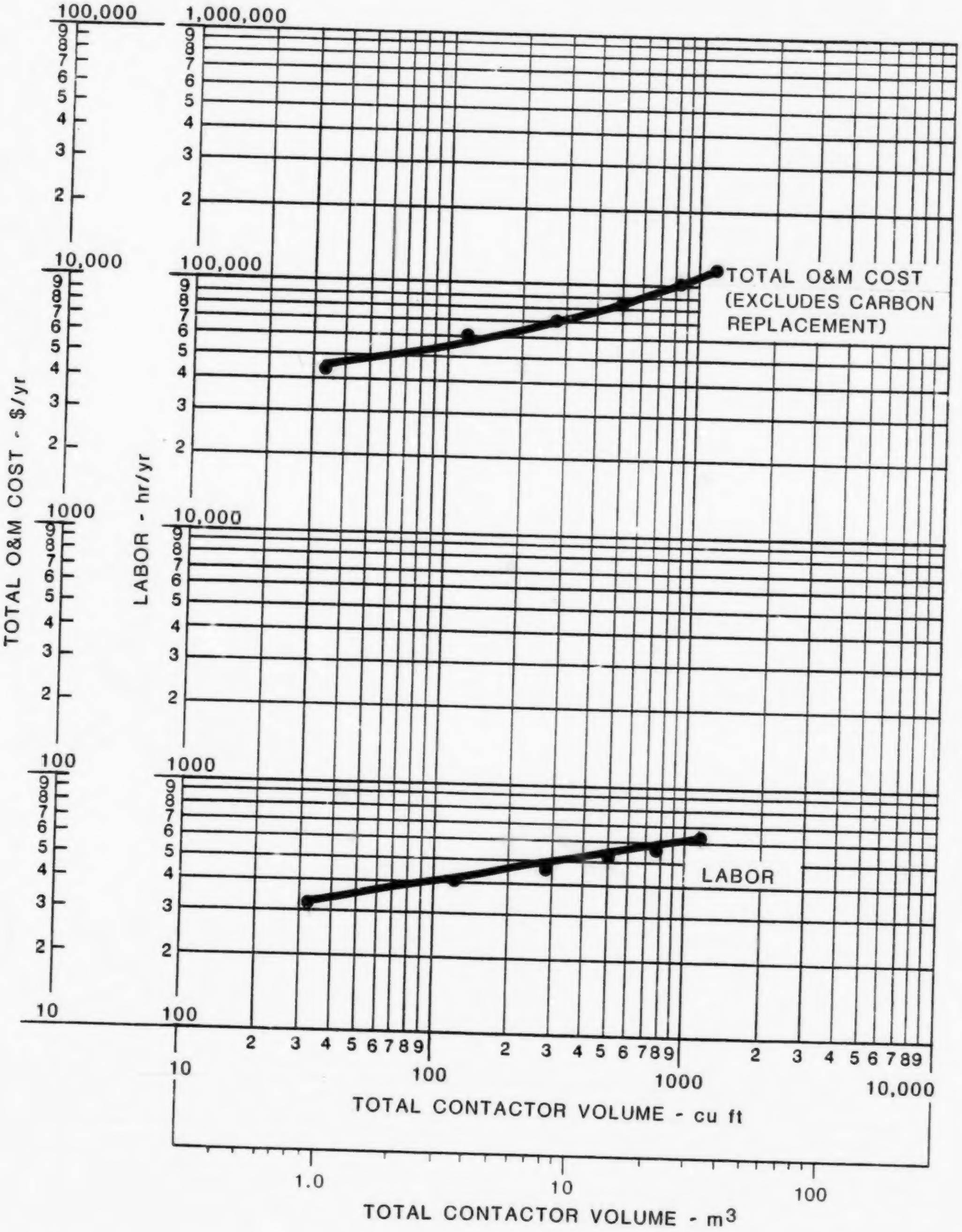


Figure 65. **Operation and maintenance requirements for package gravity granular activated carbon contactors - labor and total O&M cost.**

DIFFUSED AIR AERATION

Introduction

Diffused aeration appears to be a viable technique for removing volatile organic contaminants from water supplies. Air:water ratios ranging from 5:1 to 15:1 (volume: volume basis) have been evaluated in several pilot installations and provided acceptable reduction in concentration of a variety of volatile organic compounds. Air:water ratios higher than 15:1 are possible, but may not be economic in many situations. Organic compounds such as chlorinated hydrocarbons with relatively high Henry's Law constants are most amenable to removal by aeration. The organics are removed from the water by air stripping accomplished by injecting compressed air through submerged diffusers placed at the bottom of a tank. Incoming water is introduced at the top and treated water is removed from the bottom of the tank.

Impact of Raw Water Quality on Treatment Cost

Only recently have aeration methods for removing organics been evaluated through a limited number of pilot and full-scale testing programs. Removal is a function of the air:water ratio, diffuser type, contact time, water temperature, height of water in the contact chamber and the Henry's Law constant of the volatile organics. The ratio of depth to surface area will also have an effect, with the minimum depth at least one meter (3.28 ft). At this time, operating experience is not sufficient to establish appropriate design criteria from which treatment costs can be related to concentrations of organics in water supplies.

Construction Costs

Costs were developed for a series of diffused aeration systems using design criteria listed in Table 77. Air flow rates used in the development of costs were 0.79, 1.62, and 2.41 $m^3/min/m^2$ of aeration basin surface area (2.6, 5.3, and 7.9 scfm/sq ft). Basin depths of 2.1 and 3.7 m (7 and 12 ft) were also used in the development of costs. The systems include a factory-built, truck transportable, steel contact tank with diffusers, dual positive displacement or centrifugal blowers, blower piping and valves, and water inlet and outlet piping. The tanks are constructed of 0.64 cm (0.25 in) thick steel plate and are supported on a concrete foundation pad. The tanks are not housed.

Construction costs are presented in Tables 78, 79, and 80 and are also illustrated in Figure 66.

Operation and Maintenance Requirements and Costs

Process energy is required for operating the blowers. It was assumed that the blowers would operate continuously 24 hours a day, 365 days per year. Since the aeration tanks would not be housed, no building related energy is required.

TABLE 77. CONCEPTUAL DESIGNS FOR DIFFUSED AERATION SYSTEMS

Aeration Tank Volume, gal	No. of Tanks	Tank Dimensions		Air Flow, scfm		
		Diameter, ft	Height, ft	2.6 scfm/sq ft	5.3 scfm/sq ft	7.9 scfm/sq ft
7 ft Tank Depth						
200	1	2.5	7	13.5	27	41
600	1	4.5	7	40	80	120
1,100	1	6	7	67	133	200
2,000	1	8	7	134	267	400
3,500	1	11	7	234	467	700
7,000	1	15	7	467	933	1,400
12 ft Tank Depth						
400	1	2.5	12	13.5	27	41
1,200	1	4.5	12	40	80	120
2,200	1	6	12	67	133	200
4,000	1	8	12	134	267	400
7,000	1	11	12	234	467	700
14,000	1	15	12	467	933	1,400

Note: Tank height includes 1.5 to 2 ft freeboard.

TABLE 78. CONSTRUCTION COST SUMMARY FOR DIFFUSED AERATION SYSTEMS - 2.6 SCFM/SQ FT

Cost Category	Tank Volume, gal					
	200	600	1,100	2,000	3,500	7,000
7 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	2,100	3,700	5,900	7,200	11,800	22,500
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	700	1,100	1,800	2,200	3,600	6,800
Pipe and Valves	300	600	900	1,100	1,800	3,400
Electrical, Instrumentation	500	700	800	1,300	1,700	1,900
Subtotal	3,800	6,500	10,100	12,800	20,500	36,800
Design Contingencies	600	1,000	1,500	1,900	3,100	5,500
Total	$4,400	$7,500	$11,600	$14,700	$23,600	$42,300

Cost Category	Tank Volume, gal					
	400	1,200	2,200	4,000	7,000	14,000
12 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	2,900	5,100	7,800	9,700	15,300	26,900
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	900	1,500	2,400	2,900	4,600	8,100
Pipe and Valves	500	800	1,200	1,500	2,300	4,100
Electrical, Instrumentation	500	700	800	1,300	1,700	1,900
Subtotal	5,000	8,500	12,900	16,400	25,500	43,200
Design Contingencies	800	1,300	2,000	2,500	3,800	6,500
Total	$5,800	$9,800	$14,900	$18,900	$29,300	$49,700

TABLE 79. CONSTRUCTION COST SUMMARY FOR DIFFUSED AERATION SYSTEMS - 5.3 SCFM/SQ FT

Cost Category	Tank Volume, gal					
	200	600	1,100	2,000	3,500	7,000
7 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	2,500	4,300	6,300	11,600	20,400	35,100
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	800	1,300	1,900	3,500	6,100	10,500
Pipe and Valves	400	700	1,000	1,800	3,100	5,300
Electrical, Instrumentation	500	700	900	1,300	1,800	2,100
Subtotal	4,400	7,400	10,800	19,200	33,000	55,200
Design Contingencies	700	1,100	1,600	2,900	5,000	8,300
Total	$5,100	$8,500	$12,400	$22,100	$38,000	$63,500

Cost Category	Tank Volume, gal					
	400	1,200	2,200	4,000	7,000	14,000
12 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	3,300	5,700	8,200	14,100	23,900	39,500
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	1,000	1,700	2,500	4,300	7,200	12,900
Pipe and Valves	500	900	1,200	2,100	3,600	5,900
Electrical, Instrumentation	500	700	900	1,300	1,800	2,100
Subtotal	5,500	9,400	13,500	22,800	38,100	62,600
Design Contingencies	800	1,400	2,000	3,400	5,700	9,400
Total	$6,300	$10,800	$15,500	$26,200	$43,800	$71,000

TABLE 80. CONSTRUCTION COST SUMMARY FOR DIFFUSED AERATION SYSTEMS - 7.9 SCFM/SQ FT

Cost Category	Tank Volume, gal					
	200	600	1,100	2,000	3,500	7,000
7 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	2,800	5,300	8,400	14,900	26,200	49,600
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	900	1,600	2,500	4,500	7,900	14,900
Pipe Valves	400	800	1,300	2,200	3,900	7,400
Electrical, Instrumentation	600	800	1,100	1,500	2,100	2,200
Subtotal	4,900	8,900	14,000	24,100	41,700	76,300
Design Contingencies	800	1,300	2,100	3,600	6,300	11,500
Total	$5,700	$10,200	$16,100	$27,700	$48,000	$87,800

Cost Category	Tank Volume, gal					
	400	1,200	2,200	4,000	7,000	14,000
12 ft Tank Depth						
Excavation and Sitework	$ 100	$ 200	$ 300	$ 400	$ 600	$ 800
Manufactured Equipment	3,600	6,700	10,300	17,400	29,700	54,000
Concrete	100	200	400	600	1,000	1,400
Labor, Installation	1,100	2,000	3,100	5,200	8,900	16,200
Pipe and Valves	600	1,000	1,600	2,600	4,500	8,100
Electrical, Instrumentation	600	800	1,100	1,500	2,100	2,200
Subtotal	6,100	10,900	16,800	27,700	46,800	82,700
Design Contingencies	900	1,700	2,500	4,200	7,000	12,400
Total	$7,000	$12,600	$19,300	$31,900	$53,800	$95,100

Maintenance materials are for replacement of aeration blower components which wear out or break down during normal operation. Labor requirements cover both operation and maintenance. The majority of the labor is required for routine maintenance of the blowers. Operational requirements are minimal. An occasional adjustment of air flow may be done if either a higher or lower air:water ratio is needed to obtain the desired level of volatile organics removal.

Operation and maintenance requirements and costs are summarized in Tables 81, 82, and 83 and are also shown in Figures 67 and 68.

TABLE 81. OPERATION AND MAINTENANCE SUMMARY FOR DIFFUSED AERATION SYSTEMS 2.6 SCFM/SQ FT

Aeration Tank Volume, gal	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
7 ft Tank Depth				
200	2,900	90	65	1,000
600	9,900	130	70	1,600
1,100	14,700	180	70	2,000
2,000	29,400	310	80	3,300
3,500	49,000	600	90	5,000
7,000	88,300	1,300	110	8,700
12 ft Tank Depth				
400	4,900	90	65	1,200
1,200	16,400	130	70	2,100
2,200	24,500	180	70	2,700
4,000	49,000	310	80	4,600
7,000	81,700	600	90	7,300
14,000	147,100	1,300	110	12,800

TABLE 82. OPERATION AND MAINTENANCE SUMMARY FOR DIFFUSED AERATION SYSTEMS 5.3 SCFM/SQ FT

Aeration Tank Volume, gal	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
7 ft Tank Depth				
200	5,900	120	65	1,300
600	19,600	180	70	2,300
1,100	29,400	300	80	3,200
2,000	58,800	700	95	5,900
3,500	98,100	1,400	110	9,500
7,000	176,500	2,400	130	16,200
12 ft Tank Depth				
400	9,800	120	65	1,500
1,200	32,700	180	70	3,200
2,200	49,000	300	80	4,600
4,000	98,000	700	95	8,600
7,000	163,400	1,400	110	14,000
14,000	294,100	2,400	130	24,400

Note: Total cost in Tables 81 and 82 is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 83. OPERATION AND MAINTENANCE SUMMARY FOR DIFFUSED AERATION SYSTEMS 7.9 SCFM/SQ FT

Aeration Tank Volume, gal	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
7 ft Tank Depth				
200	8,800	140	70	1,500
600	29,400	280	80	3,200
1,100	44,100	500	90	4,600
2,000	88,200	1,000	105	8,300
3,500	147,100	1,700	120	13,300
7,000	264,700	3,600	145	23,700
12 ft Tank Depth				
400	14,700	140	70	2,000
1,200	49,000	280	80	4,600
2,200	73,500	500	90	6,600
4,000	147,000	1,000	105	12,500
7,000	245,000	1,700	120	20,200
14,000	441,100	3,600	145	36,100

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

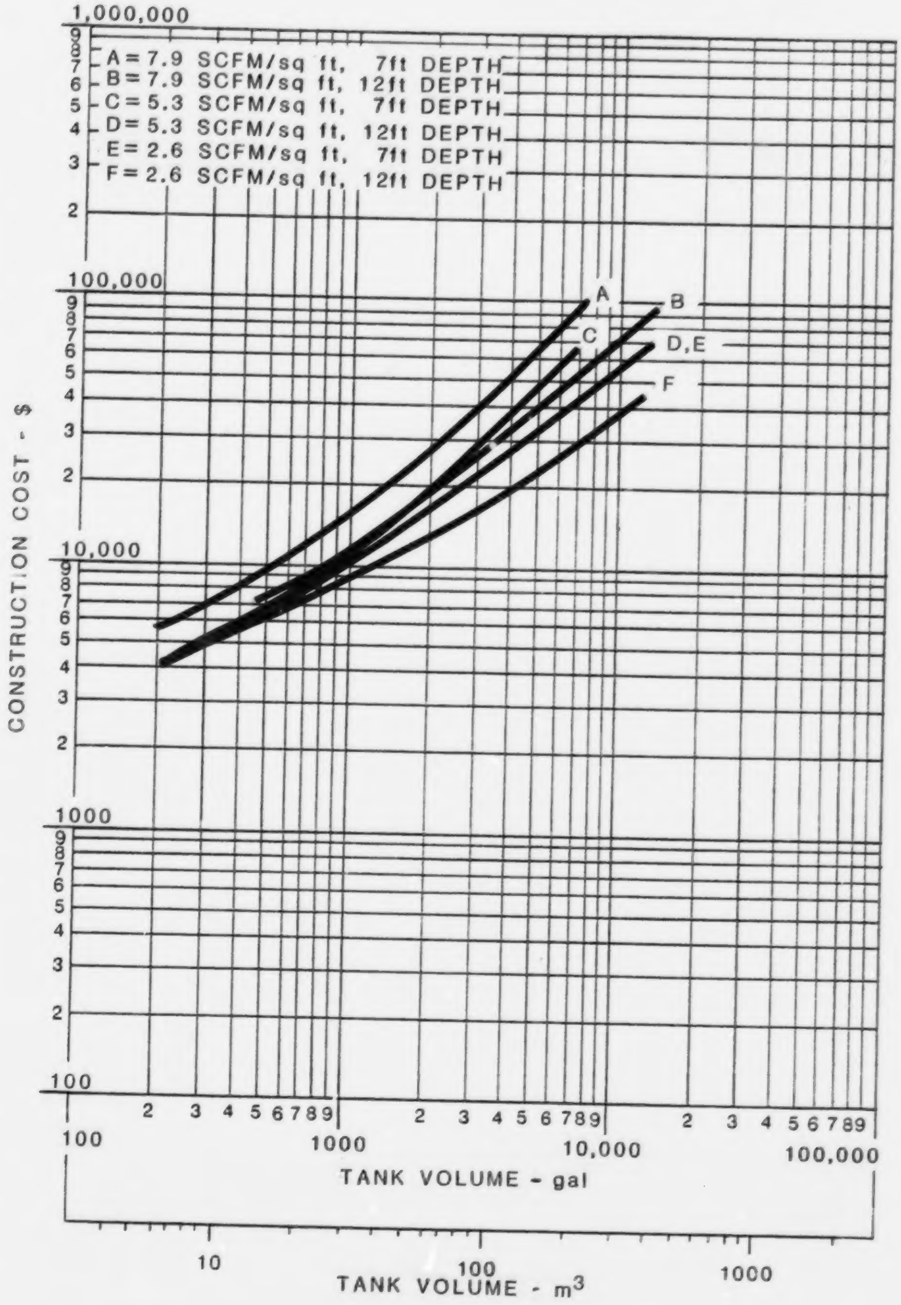


Figure 66. Construction cost for diffused aeration systems.

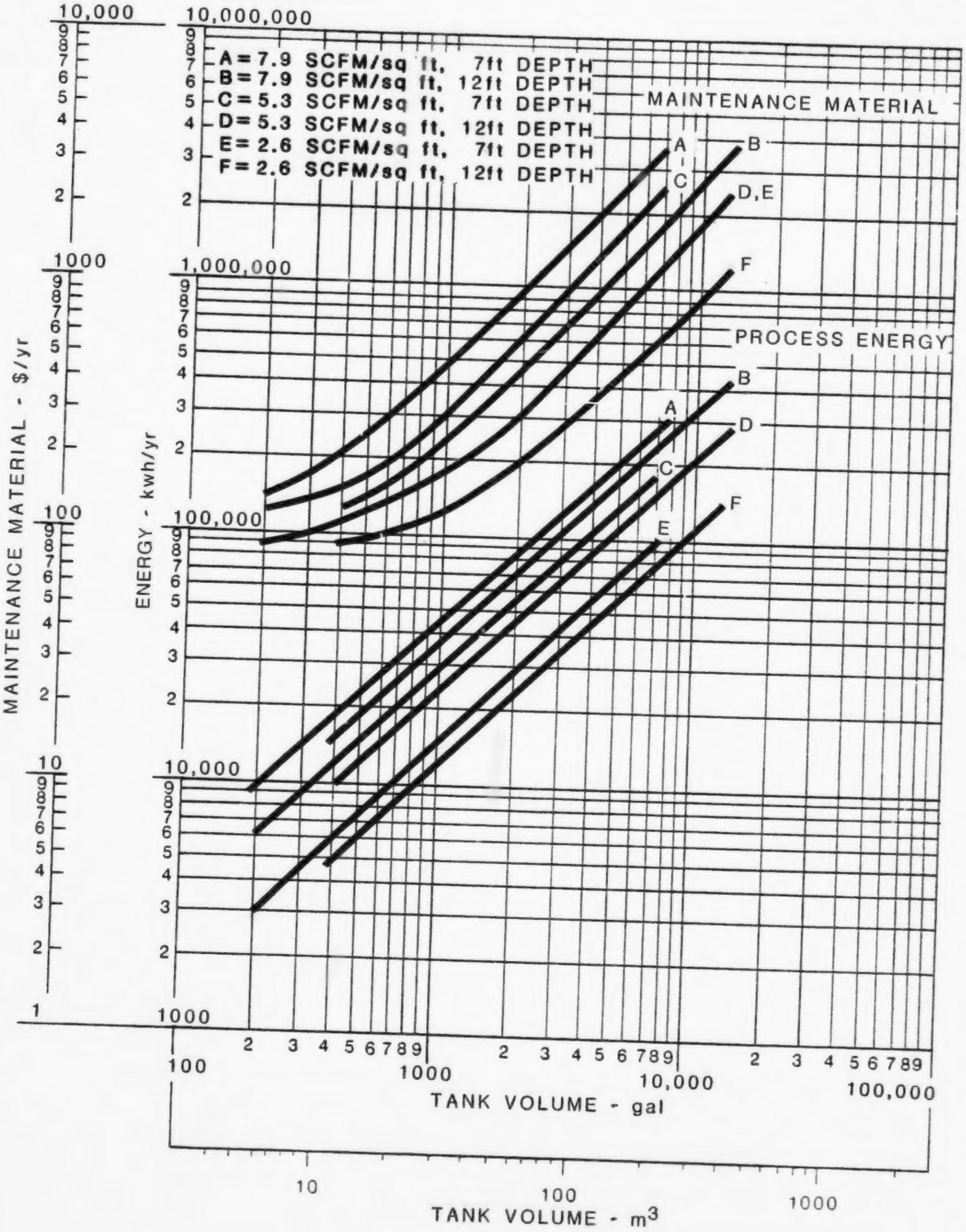


Figure 67. **Operation and maintenance requirements for diffused aeration systems – process energy and maintenance material.**

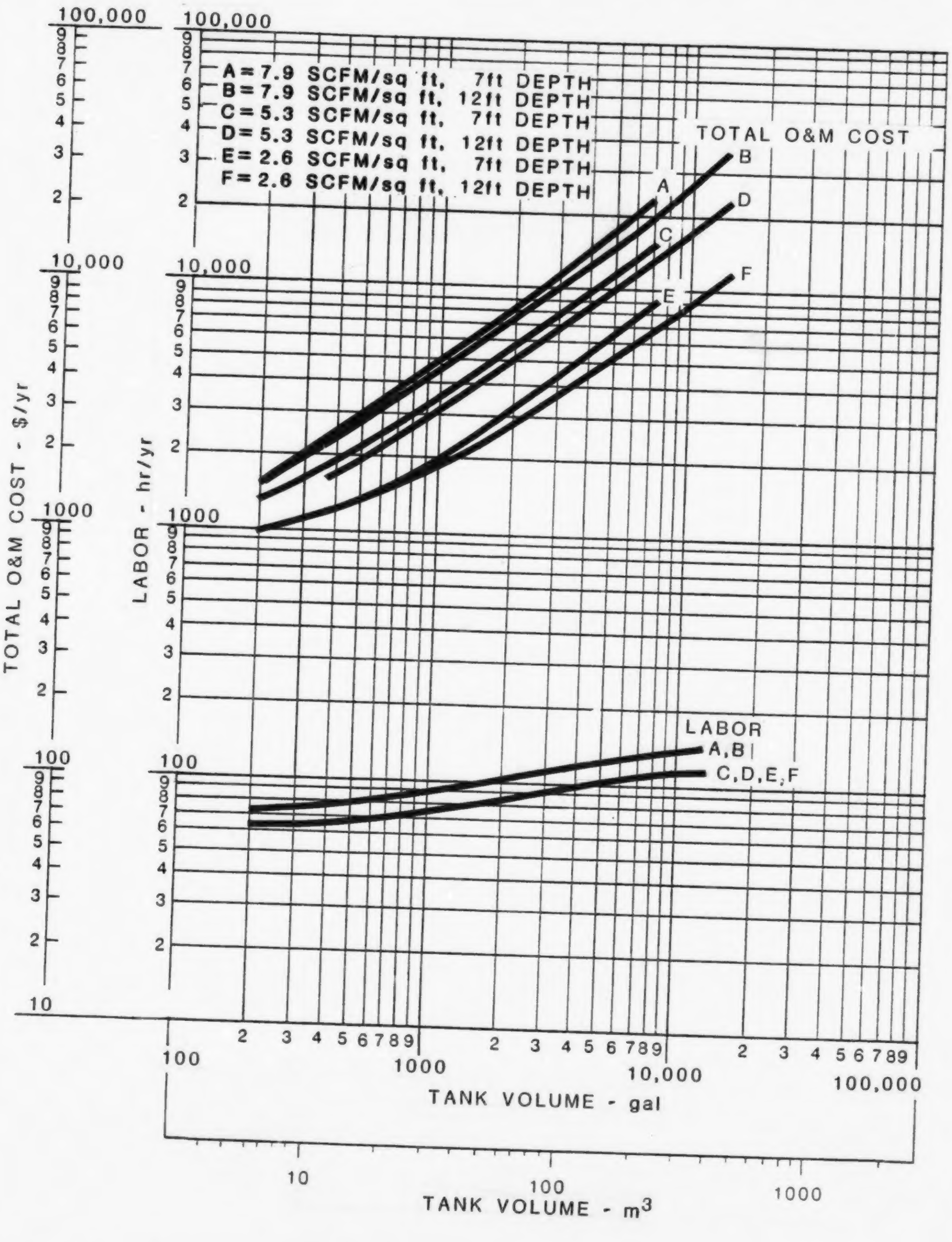


Figure 68. Operation and maintenance requirements for diffused aeration systems – labor and total O&M cost.

COUNTERCURRENT PACKED TOWER AERATION

Introduction

Countercurrent packed towers are one of the more commonly used techniques for removal of volatile organic chemicals (VOCs) from water supplies. In operation, raw water is pumped to the top of the tower, where it is uniformly distributed across the tower cross section. Water flows downward by gravity, as air supplied by a blower moves upward in the tower. To increase the surface area of water exposed to the air, the towers are filled with an inert packing material, such as Berl saddles or Raschig rings. Efficient transfer of volatile organics from the water phase to the gas phase depends upon the air/water ratio, the downward water velocity, and the depth and type of packing material. The air/water ratio is controlled by the amount of air supplied by the blower.

Impact of Raw Water Quality on Treatment Cost

Tower volume and the quantity of air supplied increase as the quantity of VOCs to be removed increases. However, different VOCs have different Henry's Law Constants, and thus vary in ease and efficiency of removal by countercurrent packed tower aeration. References 1 and 2 provide information on the impact of VOC concentration on tower design and operation. Although design equations exist, they are generally used for preliminary design, prior to conduct of pilot studies; the results of these studies being used as additional input prior to final design.

Construction Costs

Costs were developed for towers constructed of a fiberglass shell framed by structural steel. Raschig rings were used as the inert packing material. The tower is situated above a concrete sump, with gravity flow downward through the tower and into the storage sump. Included in the costs are an influent pump which pumps untreated water to the top of the tower, a flow distributor at the top of the tower, an air blower to force air into the bottom of the tower, and necessary piping and valves. A discharge pump is not included and the units are not housed.

Conceptual designs for six different size tower installations are presented in Table 84, and construction costs for these installations are presented in Table 85, Table 86 and in Figure 69. A typical installation is shown in Figure 70.

Operation and Maintenance Requirements and Costs

Process energy is required for influent pumping and for the air blower. Blower energy requirements are somewhat lower at an air:water ratio = 10:1 than at 20:1, due to the smaller blowers used at the lower air:water ratio. Discharge pumping from the product water storage sump is not included in the process energy.

TABLE 84. CONCEPTUAL DESIGNS FOR COUNTERCURRENT PACKED TOWER AERATION

Plant Capacity, gpd	Tower Design			Sump Dimensions, WxLxH, ft	Influent Pump, hp	Blower			
	Volume, cu ft	Diameter, ft	Height, ft			Air:Water = 10:1		Air:Water = 20:1	
						scfm	hp	scfm	hp
29,000	12.6	1	20	3.5x3.5x4	0.5	30	0.25	55	0.25
64,000	28	1.5	20	5x5x5	1.0	60	0.25	120	0.5
115,000	50	2	20	6x6x6	3	110	0.5	215	0.75
345,000	154	3.5	20	7.5x7.5x6	5	320	1.0	640	1.5
706,000	314	5	20	9x9x8	10	660	1.5	1,310	3.0
1,000,000	453	6	20	10x10x8	15	930	2.5	1,860	5.0

Note: Height of packing media is 16 ft, and freeboard is 4 ft. Tower volume is calculated using height of packing media.

TABLE 85. CONSTRUCTION COST SUMMARY FOR COUNTERCURRENT PACKED TOWER AERATION AIR:WATER RATIO = 10:1

Cost Category	Tower Volume, cu ft					
	12.6	28	50	154	314	453
Excavation and Sitework	$ 1,200	$ 1,200	$ 1,200	$ 1,500	$ 2,500	$ 3,000
Manufactured Equipment	8,000	8,000	9,400	13,000	16,900	19,700
Concrete	1,500	2,900	4,000	5,300	8,000	9,500
Steel	4,800	5,500	6,000	6,500	7,000	7,300
Labor, Installation	2,700	2,800	3,000	3,300	3,500	3,900
Pipe and Valves	700	800	800	1,000	1,500	2,000
Electrical, Instrumentation	2,000	2,000	2,000	2,000	2,500	2,500
Subtotal	20,900	23,200	26,400	32,600	41,900	47,900
Design Contingencies	3,200	3,500	4,000	4,900	6,300	7,200
Total	$24,100	$26,700	$30,400	$37,500	$48,200	$55,100

TABLE 86. CONSTRUCTION COST SUMMARY FOR COUNTERCURRENT PACKED TOWER AERATION AIR:WATER RATIO = 20:1

Cost Category	Tower Volume, cu ft					
	12.6	28	50	154	314	453
Excavation and Sitework	$ 1,200	$ 1,200	$ 1,200	$ 1,500	$ 2,500	$ 3,000
Manufactured Equipment	8,000	9,400	11,600	16,900	21,600	30,900
Concrete	1,500	2,900	4,000	5,300	8,000	9,500
Steel	4,800	5,500	6,000	6,500	7,000	7,300
Labor, Installation	2,700	3,000	3,300	3,500	4,100	4,300
Pipe and Valves	700	800	800	1,000	1,500	2,000
Electrical, Instrumentation	2,000	2,000	2,000	2,000	2,500	2,500
Subtotal	20,900	24,800	28,900	36,700	47,200	59,500
Design Contingencies	3,100	3,700	4,300	5,500	7,100	8,900
Total	$24,000	$25,800	$32,200	$42,200	$54,300	$68,400

Maintenance material includes cost for replacement or repair of components which wear out or break down during normal operation. Typically, this would include maintenance of the influent pump, air blower, valving, and instrumentation.

Labor is required for routine operation, as well as for maintenance of equipment. Operational labor is low however, because there are no process parameters which are normally varied once the towers are operating satisfactorily.

Operation and maintenance requirements and costs are summarized in Table 87 and are presented in Figures 71 and 72.

Field Data Collection

Packed tower aerator operating data were collected at German Valley, Illinois, Rockaway Township, New Jersey, and Wurtsmith AFB. Design and operating flow rates at these plants are:

Plant	Design Flow Rate	Operating Rate
German Valley	379 m^3/d (0.1 mgd)	125.6 m^3/d (0.033 mgd)
Rockaway Township	4,164 m^3/d (1.1 mgd)	3,590 m^3/d (0.949 mgd)
Wurtsmith AFB	5,178 m^3/d (1.368 mgd)	5,178 m^3/d (1.368 mgd)

The design air:water ratio at these plants is unknown.

A comparison of operation and maintenance requirements at these three plants and the requirements from Figures 71 and 72 is shown following:

	German Valley		Rockaway Township		Wurtsmith AFB	
	Field Data	Data From Figures 71 and 72	Field Data	Data From Figures 71 and 72	Field Data	Data From Figures 71 and 72
Electrical Energy, kwh/hr						
Process	-	4,000	-	130,000	-	170,000
Building	-	0	-	0	-	0
Total	5,300	4,000	474,700	130,000	164,000	170,000
Maintenance Material, $/yr	50	280	200	800	-	1,000
Labor, hr/yr	94	180	2,341	380	230	460

Field data and Figures 71 and 72 correlate satisfactorily except for Rockaway Township. Actual energy requirements at Rockaway Township are high because they include product water pumping, but there is no apparent reason for the high labor requirement, other than incorrect allocation of labor between different unit process.

TABLE 87. OPERATION AND MAINTENANCE SUMMARY FOR COUNTERCURRENT PACKED TOWER AERATORS

Average Plant Flow Rate, gpd	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
Air:Water Ratio = 10:1				
29,000	4,900	270	183	2,600
64,000	8,200	290	183	2,900
115,000	23,900	320	183	4,000
345,000	39,200	450	200	5,400
706,000	75,200	570	280	8,900
1,000,000	114,400	790	365	12,800
Air:Water Ratio = 20:1				
29,000	4,900	270	183	2,600
64,000	9,800	290	183	3,000
115,000	24,500	320	183	4,100
345,000	42,500	450	200	5,600
706,000	85,000	570	280	9,600
1,000,000	130,700	790	365	14,000

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

References

1. Love, O.T. Jr. et. al, "Treatment of Volatile Organics Compounds in Drinking Water," EPA-600/8-83-019, U.S. Environmental Protection Agency, Cincinnati, Ohio, May 1983, p. 105.

2. Kavanaugh, M.C. and Trussell, R.R., "Design of Aeration Towers to Strip Volatile Contaminants From Drinking Water," Journal AWWA, December 1980, p. 684.

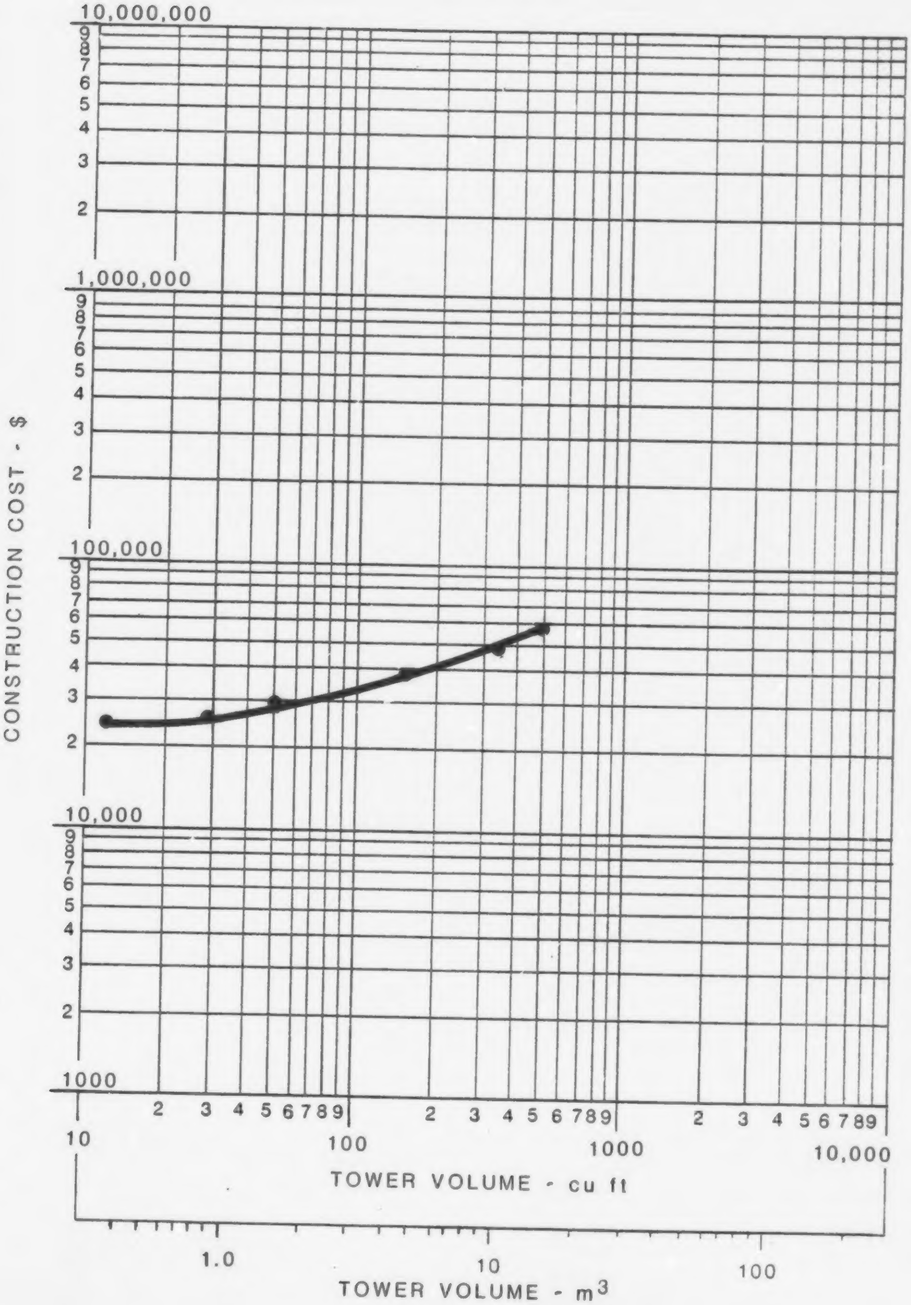


Figure 69. **Construction cost for countercurrent packed tower aerators.**

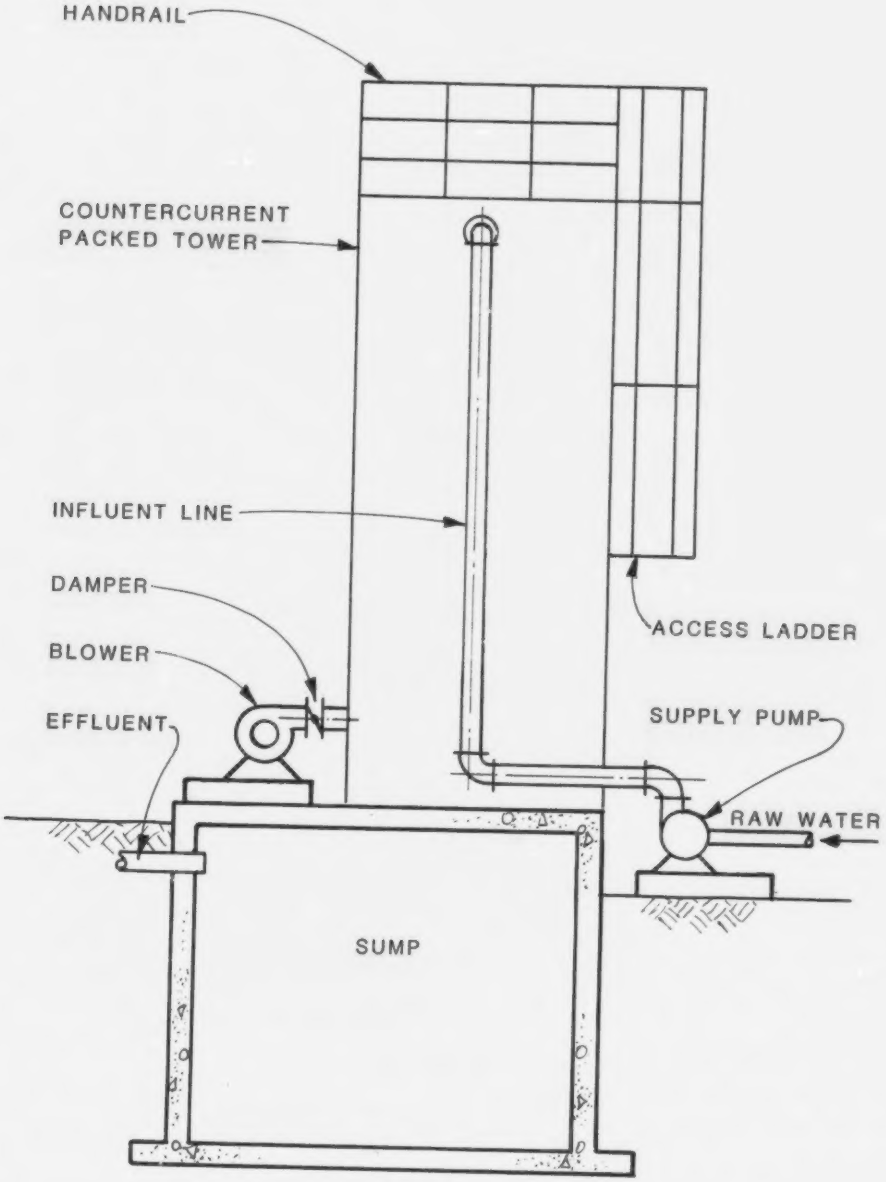

HANDRAIL
COUNTERCURRENT PACKED TOWER
INFLUENT LINE
DAMPER
BLOWER
EFFLUENT
ACCESS LADDER
SUPPLY PUMP
RAW WATER
SUMP

Figure 70. Countercurrent packed tower.

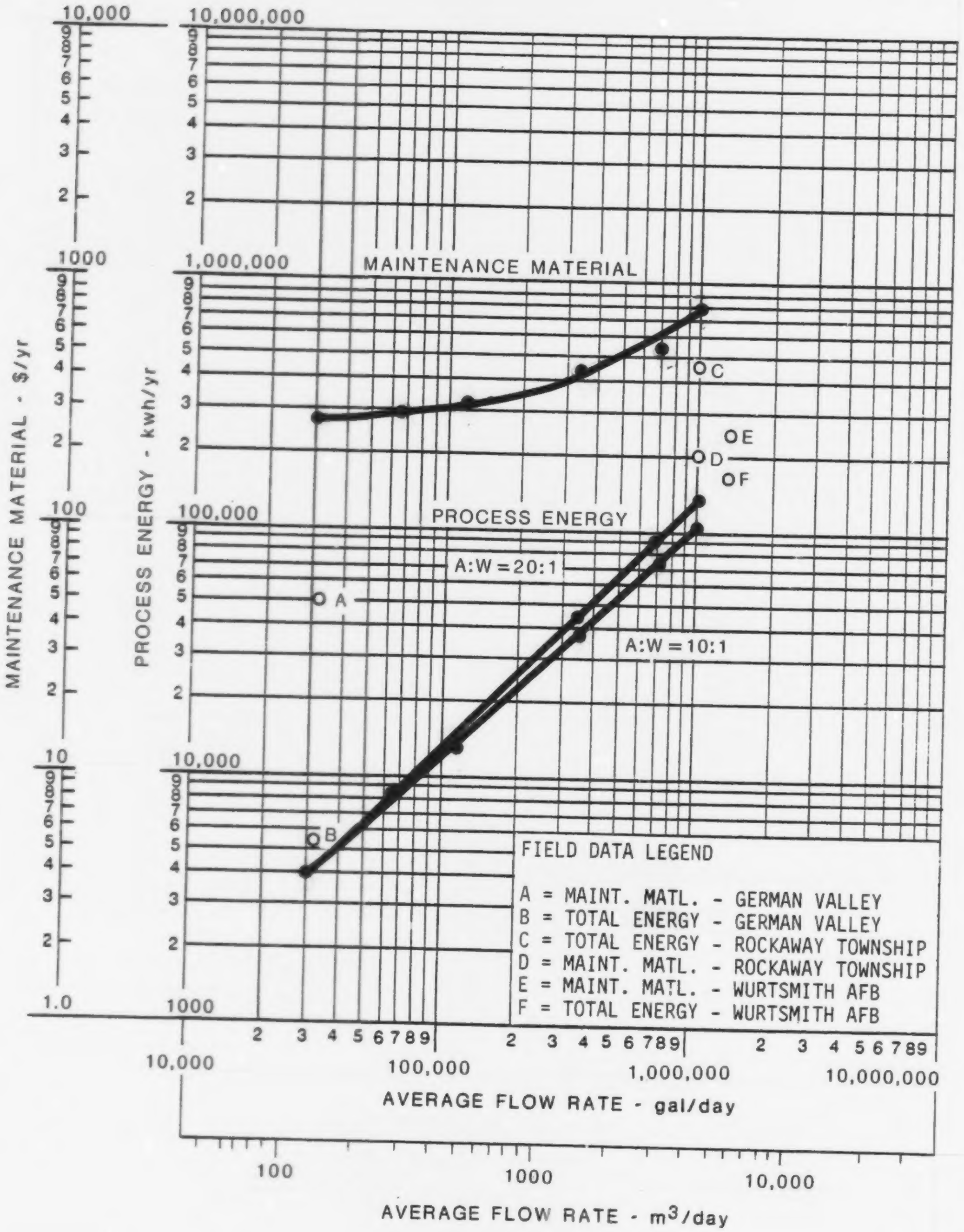


Figure 71. **Operation and maintenance requirements for countercurrent packed tower aerators - process energy and maintenance material.**

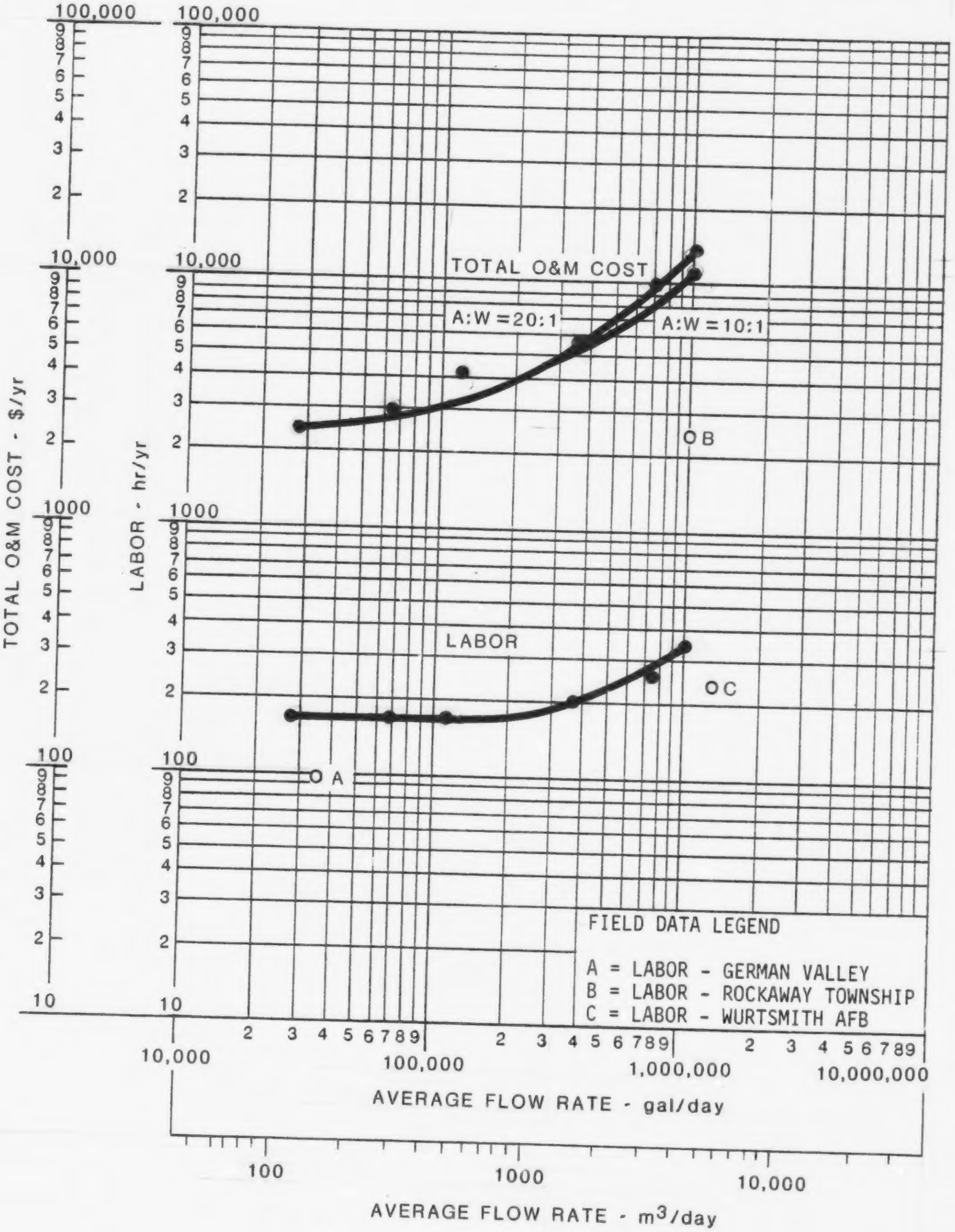


Figure 72. **Operation and maintenance requirements for countercurrent packed tower aerators - labor and total O&M costs.**

SPRAY AERATION SYSTEMS

Introduction

Spray aeration may be used to remove volatile substances such as oxygen, carbon dioxide, hydrogen sulfide, methane and volatile organic compounds. Installations commonly consist of fixed nozzles on a pipe grid placed over a shallow basin or pond. The nozzles direct the water upward breaking the water into small droplets, exposing a large surface area, which permits rapid transfer of volatile substances from the water to the atmosphere. The size of the droplets created by the spray nozzles is an important factor affecting transfer efficiency; smaller droplets result in greater transfer efficiency.

Efficiency of spray aeration is also highly dependent upon water and air temperature. At low air temperatures removal efficiencies are greatly reduced and where winter icing occurs, spray aeration systems are not suitable. Because of the large area requirements for spray aeration systems, it is not economical to house the ponds.

Impact of Raw Water Quality on Treatment Cost

Operating installations using spray aeration for removal of synthetic volatile organic compounds from surface or ground waters are limited. Highly volatile organic compounds with high Henry's Law constants can probably be removed quite effectively by a spray aeration system when air temperatures are warm. Efficiency will decrease with lowering air and water temperature.

Construction Costs

Costs were developed for a series of single-pass spray aeration systems using design criteria listed in Table 88. The system consists of a 0.91 m (3 ft) deep, membrane lined, collection basin over which a pipe grid with "whirl-jet" nozzles are installed. The nozzles are located at 3.1 m (10 ft) centers and distribute incoming water at a pressure of 1.05 kg/cm^2 (15 psi). The nozzles are positioned about 0.91 m (3 ft) above the water surface which provides an exposure time of about one second for the falling droplets.

The basins, which have a sideslope of 3:1, are totally surrounded by a 1.8 m (6 ft) tall, drift containment barrier supported on a 0.61 m (2 ft) tall, perimeter wall. The costs include dual supply pumps (unhoused), an earthen basin with membrane liner, distribution piping over the basin, piping supports, nozzles, and outlet piping to the edge of the embankment. Construction costs are summarized in Table 89 and are also presented in Figure 73.

Operation and Maintenance Requirements and Costs

Process energy is required for operating the aeration system supply pumps. It is assumed that the supply pumps operate continuously 24 hours a day, 365 days per year, and supply water to the nozzles at a pressure of 1.05 kg/cm^2 (15 psi). Since the basins are not housed, no building related energy is required.

TABLE 88. CONCEPTUAL DESIGNS FOR SPRAY AERATION SYSTEMS

Plant Capacity, gpd	Pond Dimensions, LxWxD, ft	Number of Spray Nozzles	Flow/Nozzle, gpm	Supply Pump, hp
28,000	40x40x3	4	5	1/2
72,000	40x65x3	8	5	3/4
200,000	40x90x3	12	10	3
504,000	90x90x3	16	22	10
1,008,000	90x90x3	16	44	15

Notes: 1. Operating pressure is 15 psi.
2. Supply pumping horsepower requirements are based upon a single pass system with no recycle.

TABLE 89. CONSTRUCTION COST SUMMARY FOR SPRAY AERATION SYSTEMS

Cost Category	Plant Capacity, gpd 28,000	72,000	200,000	504,000	1,008,000
Excavation and Sitework	$11,300	$15,600	$19,600	$35,100	$35,100
Manufactured Equipment	800	900	1,300	2,700	3,900
Concrete	4,400	5,600	6,000	7,900	8,000
Labor, Installation	2,400	2,700	3,600	7,000	9,000
Pipe and Valves	1,300	1,600	2,300	4,500	6,200
Electrical Instrumentation	1,600	2,100	2,500	4,000	5,000
Subtotal	21,800	28,500	35,300	61,200	67,200
Design Contingencies	3,300	4,300	5,300	9,200	10,100
Total	$25,100	$32,800	$40,600	$70,400	$77,300

Maintenance material includes replacement of pump components which wear out under normal service conditions. Labor requirements include both operation and maintenance. The majority of the labor is required for maintenance of the supply pumps. Operational adjustments and requirements are minimal. Floating debris must be removed from the basin and nozzles may need occassional cleaning, depending upon the characteristics of the water being aerated. Operation and maintenance requirements and costs are summarized in Table 90 and are also shown in Figures 74 and 75.

TABLE 90. OPERATION AND MAINTENANCE SUMMARY FOR SPRAY AERATION SYSTEMS

Plant Capacity, gpd	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
28,000	2,400	80	50	800
72,000	6,100	120	60	1,200
200,000	17,200	180	80	2,300
504,000	42,900	400	100	4,500
1,008,000	85,900	650	120	8,000

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

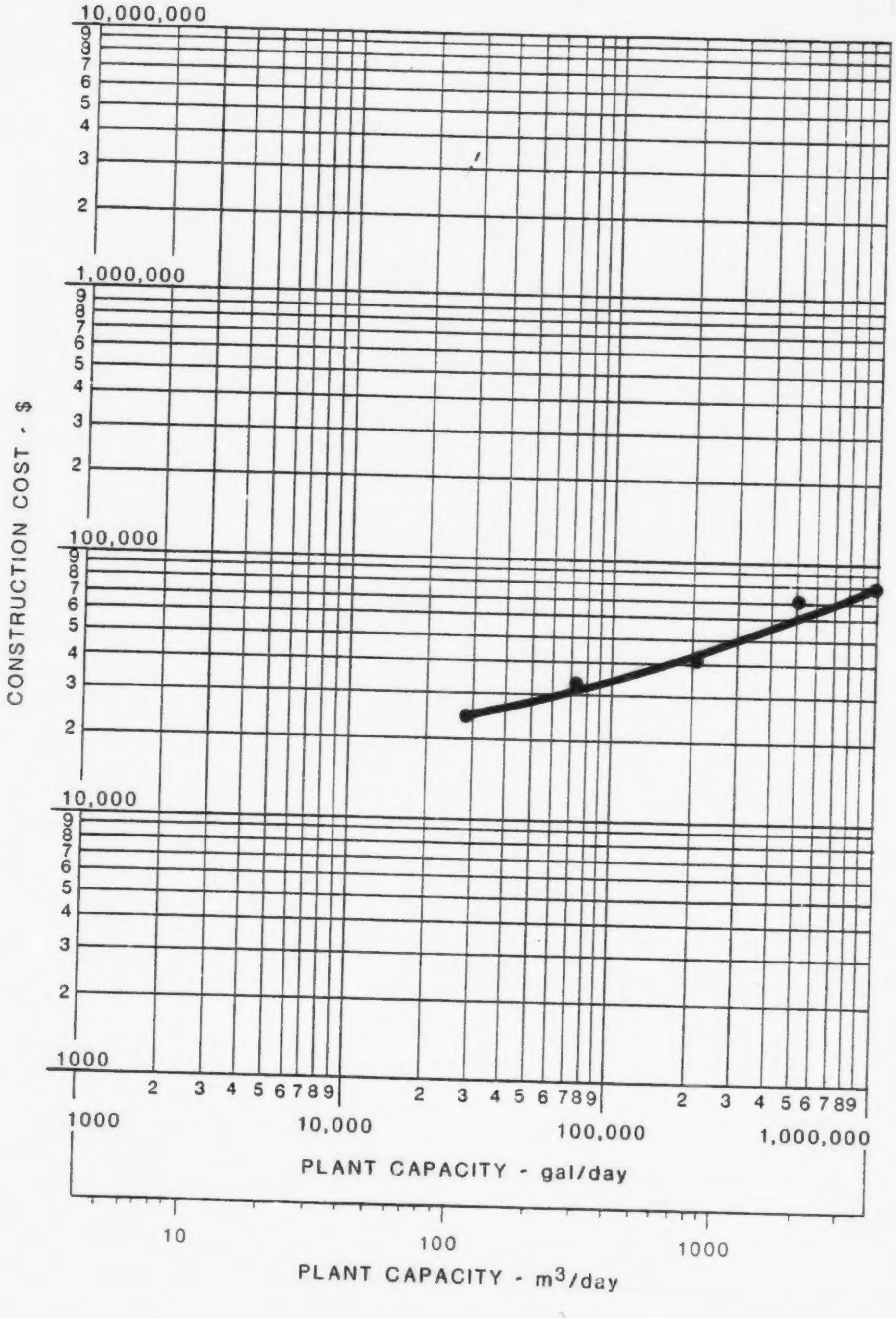


Figure 73. Construction costs for spray aeration systems.

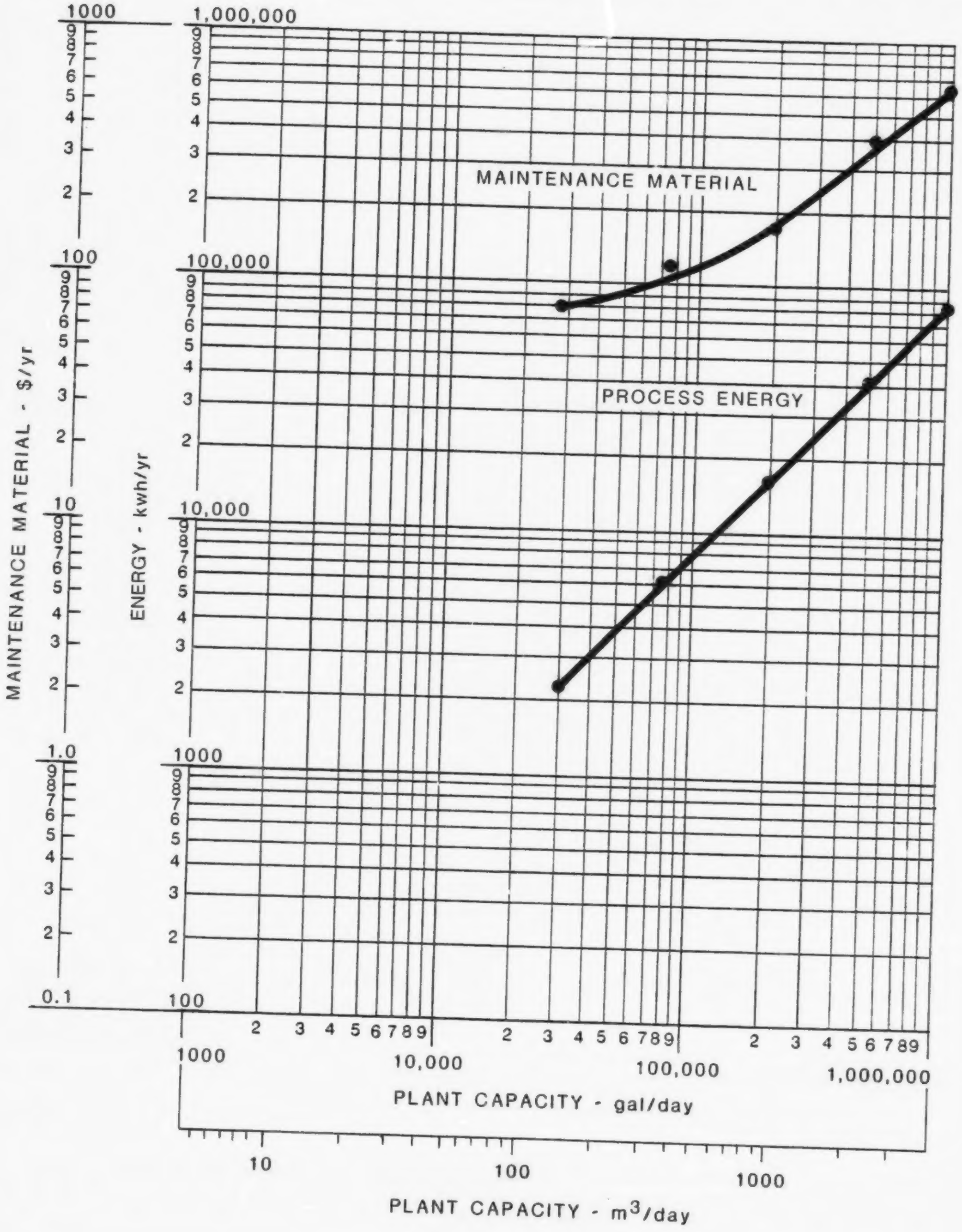


Figure 74. **Operation and maintenance requirements for spray aeration systems - process energy and maintenance material.**

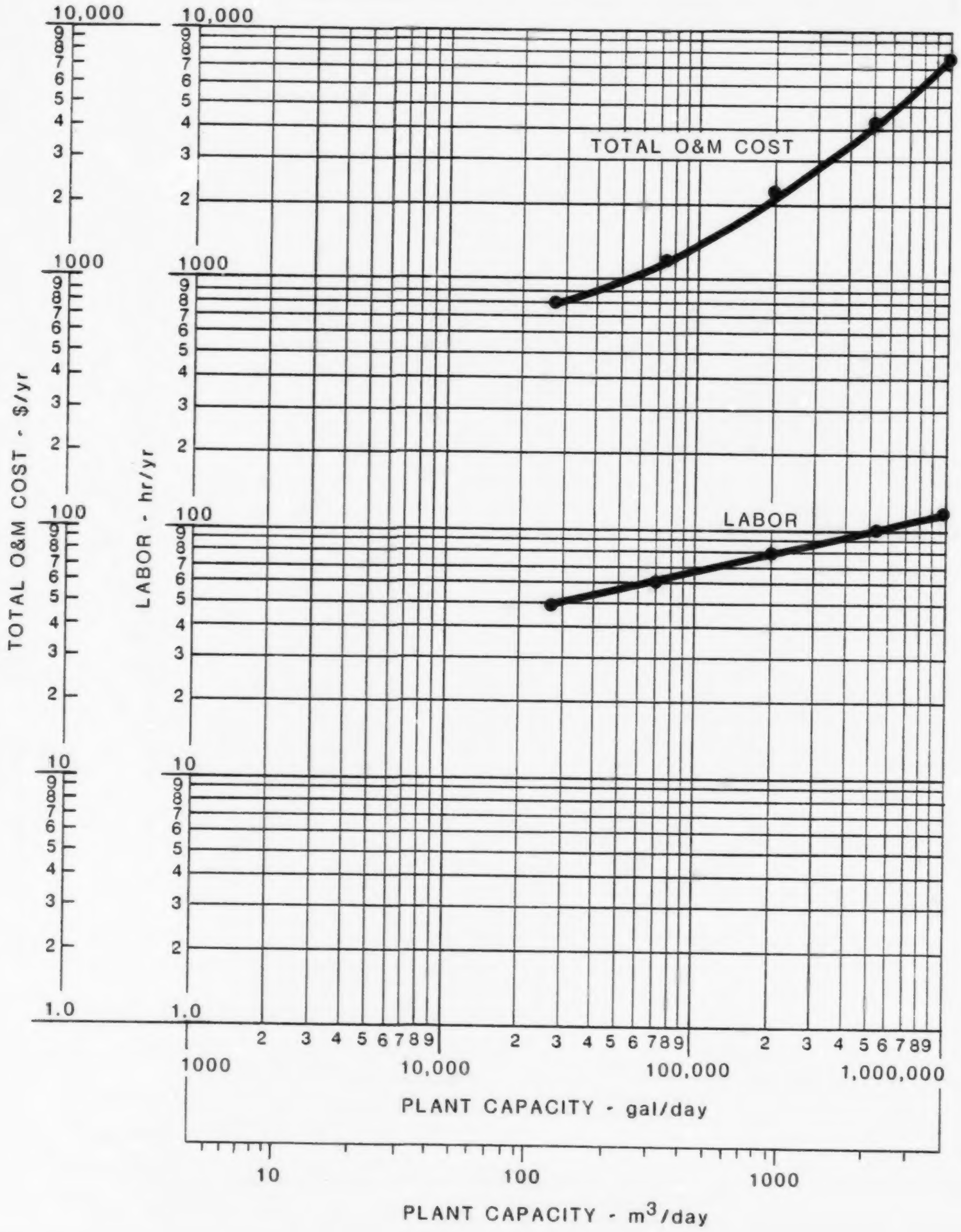


Figure 75. **Operation and maintenance requirements for spray aeration systems - labor and total O&M cost.**

42.2

CASCADE TRAY AERATORS

Introduction

Cascade, tray-type aerators are simple, low maintenance systems which may have application in some cases for removal of volatile organic compounds. This type of aerator is similar to coke tray aerators which are used for the removal of hydrogen sulfide, iron, and manganese. In operation, water is pumped to the top tray, dispersed across the tray surface, and then trickles downward through several lower trays. One difficulty, relative to the design of such systems, is that the air:water ratio can not be controlled.

Impact of Raw Water Quality on Treatment Cost

High volatile organic chemical (VOC) concentrations, or the presence of difficult to remove VOCs, will require an increase in total tray surface area. This will increase capital cost, but will have minimal impact on operation and maintenance cost, unless series operation is necessary, which would require multiple pumping.

Construction Costs

The conceptual designs, as shown in Table 91, are patterened after coke tray type aerators. Units consist of four trays spaced at 33 cm (13 in) intervals and the aerator is situated above a concrete storage sump. Aerator loadings, expressed in gpm/sq ft of tray area were gradually increased with aerator size, due to an assumed increase in removal efficiency for the larger units. The construction costs include the tray aerator, supply piping, influent pump, and concrete storage sump. Discharge pumps are not included, and the units are not housed. Construction costs are summarized in Table 92 and are also presented in Figure 76.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements are low for tray aerators, due to the simplicity and reliability of process design, and due to relatively low electrical requirements, which are only for pumping raw water to the top of the aerator. Maintenance material is for replacement of components which wear out or break down during normal operations.

Labor requirements are for periodic monitoring of process operation, and general maintenance as required. Due to the overall reliability of this process, daily monitoring is not required.

Operation and maintenance requirements are summarized in Table 93 and are presented in Figures 77 and 78.

TABLE 91. CONCEPTUAL DESIGN CRITERIA FOR CASCADE TRAY AERATORS

Plant Capacity, gpd	Number of Trays	Size of Trays, WxL, ft	Loading gpm/sq ft of tray area	Sump Dimensions, WxLXD, ft	Influent Pump, hp
65,000	4	3x3	1.25	5x5x5	0.25
115,000	4	4x4	1.25	6x6x6	0.50
345,000	4	6.5x6.5	1.42	7.5x7.5x6	1.5
706,000	4	9x9	1.51	9x9x8	3
1,000,000	4	10x10	1.74	10x10x8	4

TABLE 92. CONSTRUCTION COST SUMMARY FOR CASCADE TRAY AERATORS

	Plant Capacity, gpd				
Cost Category	65,000	115,000	345,000	706,000	1,000,000
Excavation and Sitework	$ 1,100	$ 1,200	$ 1,500	$ 2,500	$ 3,000
Manufactured Equipment	5,300	5,600	5,900	17,600	17,900
Concrete	3,300	4,000	5,300	8,000	9,500
Labor, Installation	5,100	5,500	6,000	7,000	7,500
Pipe and Valves	800	800	1,000	1,500	2,000
Electrical, Instrumentation	2,000	2,000	2,000	2,500	2,500
Subtotal	17,600	19,100	21,700	39,100	42,400
Design Contingencies	2,700	2,900	3,300	5,900	6,400
Total	$20,300	$22,000	$25,000	$45,000	$48,000

TABLE 93. OPERATION AND MAINTENANCE SUMMARY FOR CASCADE TRAY AERATORS

Average Plant Flow Rate, gpd	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
65,000	1,600	180	100	1,400
115,000	3,300	200	100	1,500
345,000	9,800	230	120	2,300
706,000	15,600	310	130	2,900
1,000,000	26,100	400	140	3,800

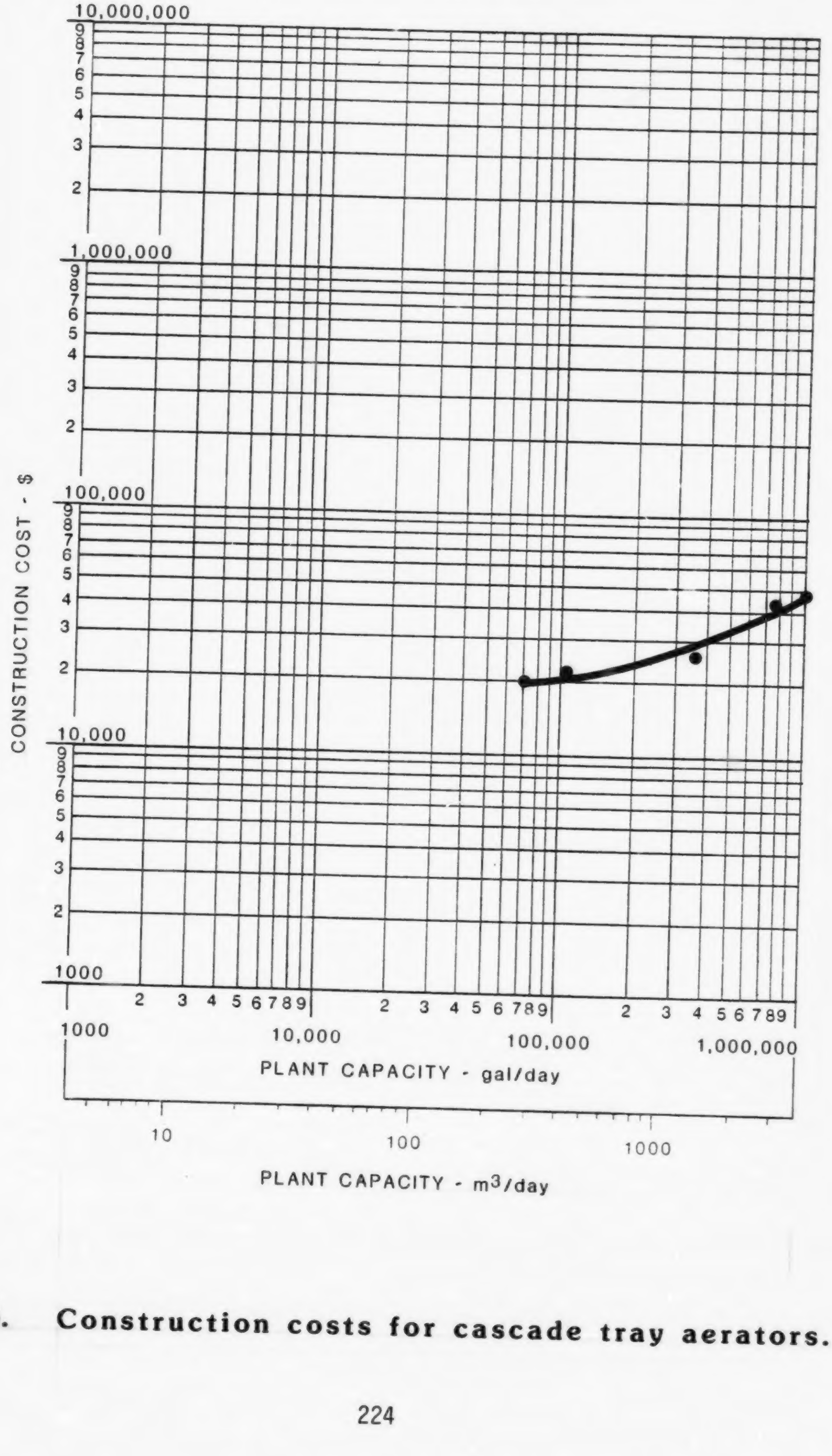


Figure 76. Construction costs for cascade tray aerators.

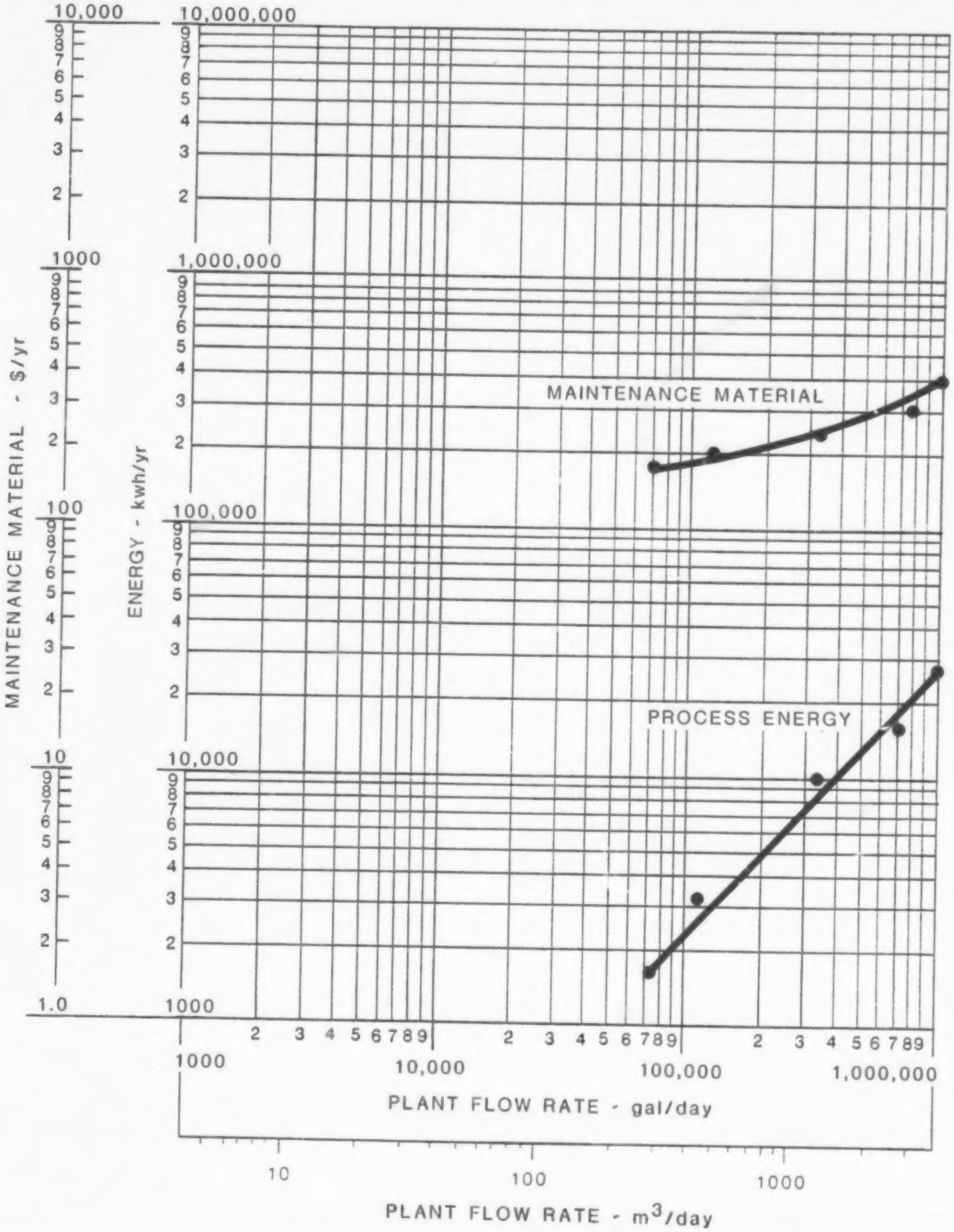


Figure 77. Operation and maintenance requirements for cascade tray aerators - process energy and maintenance material.

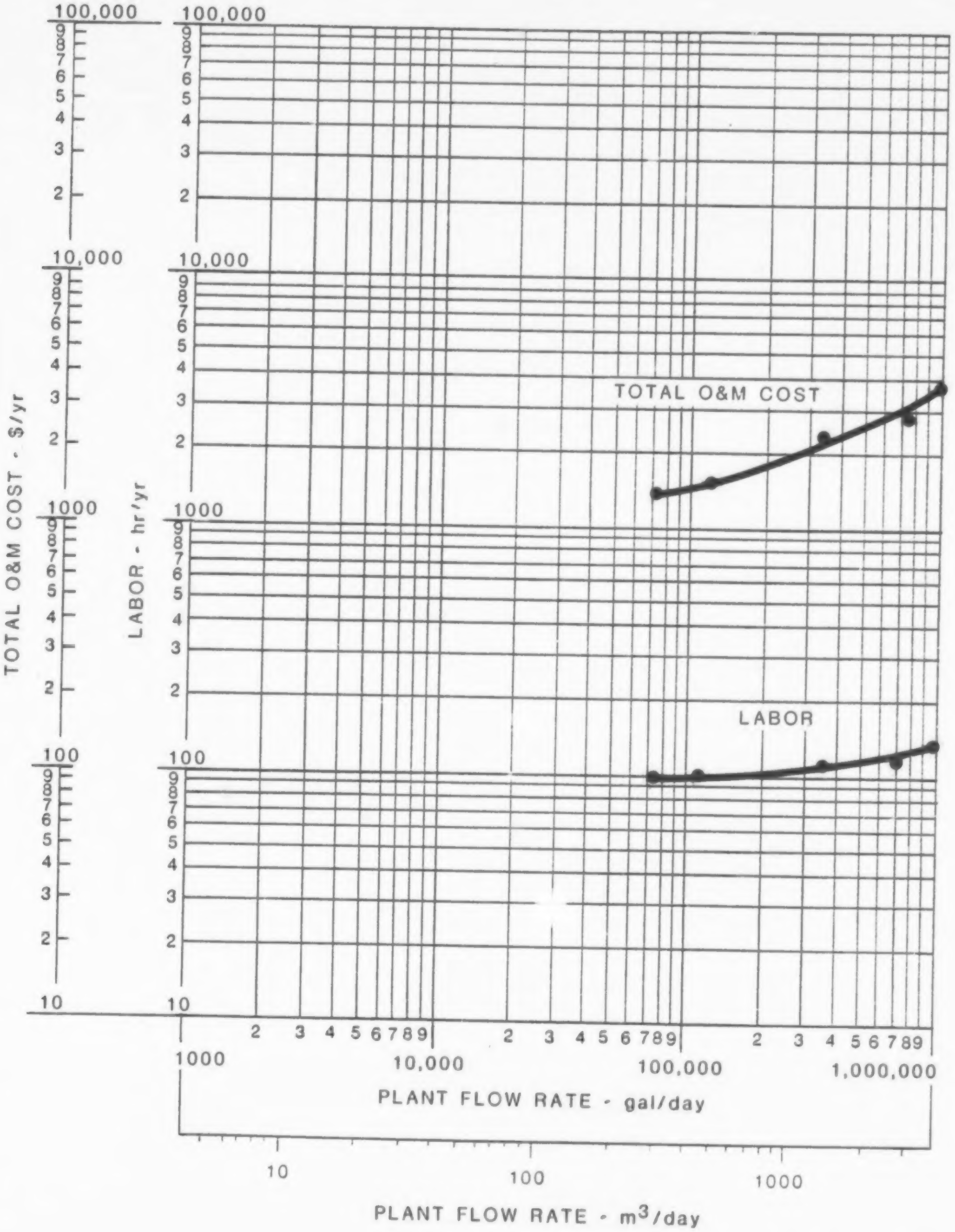


Figure 78. **Operation and maintenance requirements for cascade tray aerators - labor and total O&M cost.**

GAS FEED CHLORINATION SYSTEMS

Introduction

Essential components of gaseous chlorination systems are the chlorine cylinder, a chlorinator, an injector, and a high pressure water supply to operate the injector. For chlorination of a pipeline supply, a booster pump is used to supply the high pressure water to the injector. This booster pump draws suction from the pipeline, increasing the pressure of this withdrawn water, which is then passed through the injector and back into the pipeline. The injector creates a vacuum which draws chlorine gas into the high pressure water, creating a chlorine solution. A check valve is located in the ejector to prevent chlorine addition when the booster pump is not operating.

For chlorination of a well supply, two methods can be used. The first is identical to that discussed for chlorinating a pipeline supply, with the booster pump drawing suction after the pump discharge check valve. In the second method, water is withdrawn between the pump and the check valve, passed through the injector, and the chlorine solution is then applied down the well at least ten feet below the pump. This latter method is advantageous because it does not require a booster pump and because it provides longer detention time.

At the injector, chlorine gas passes readily into solution. The two chlorine species present after solution are hypochlorous acid (HOCl) and hypochlorite ion (OCl-). The former is a strong disinfectant which predominates at pH less than 7.5, and the latter is a weaker disinfectant, which predominates above pH 7.5.

Impact of Raw Water Quality on Treatment Cost

In addition to being a disinfectant, the hypochlorous acid which is formed by the reaction of chlorine gas and water, is an oxidant. Thus, the presence of oxidizable organics, oxidizable inorganics such as reduced forms of iron and manganese, ammonia, or other reducing compounds will increase the chlorine demand of the water, and therefore the cost of chlorination. To determine appropriate dosages, it is necessary to conduct chlorine demand tests on samples of the water to be treated.

Formation of trihalomethanes (THMs) is another consideration which can influence costs. If THM precursors are present in the raw water, concentrations of THMs in excess of the 0.1 mg/L MCL may be formed during treatment or in the distribution system. This may require a reduction in the chlorine dosage, a change in the point of chlorine addition, or in some cases, the use of an alternate disinfectant. Such changes would likely affect treatment cost. Although changing treatment techniques would probably increase treatment cost, many large utilities which have moved the point of chlorination to after sedimentation have found that the change reduced the required chlorine dosage, and consequently the operating cost.

Construction Cost

Construction costs include the chlorine manifold piping, a chlorinator, a booster pump, and the injector. For chlorine use rates less than 18.2 kg/d (40 lb/day), which is the maximum delivery rate of a 68.1 kg (150 lb cylinder), a two cylinder scale is provided to determine weight of chlorine remaining. For delivery rates between 18.2 and 36.3 kg/d (40 and 80 lb/day), four 68.1 kg (150 lb) cylinders were considered to be used, with two parallel systems of two cylinders each, and an automatic switchover between cylinders. In addition to the connected cylinders, storage area is provided for four additional cylinders, which usually will be several empty and several full containers.

The chlorinator, booster pump, injector, and other facilities are located in a 3.05 meter by 3.05 meter (10 foot by 10 foot) building. The chlorinators may be located either on the chlorine cylinder, or on an adjacent wall. A ventilation system is included which will provide up to 30 air changes per hour, and this system can be used in the event of a chlorine leak. Louvers and an automatic damper are required parts of the ventilation system. For safety considerations, a chlorine leak detector is installed in the room, and protective respiratory apparatus (oxygen rebreathing type) is provided.

Piping and valves are required for the booster pump and injector system, and between the chlorinator and the injector. Construction costs are summarized in Table 94 for smaller systems without automatic changeover, and the larger systems with automatic cylinder changeover components. A typical process layout is shown in Figure 79 and construction costs are presented in Figure 80.

Operation and Maintenance Requirements and Costs

Process energy requirements are for the booster pump. This pump is sized to pump against a pressure of 10.55 kg/cm^2 (150 psi), with required capacity varying between 0.35 and 0.66 L/s (5.5 and 10.5 gpm), depending upon the chlorine dosage. Building energy requirements are for lighting, heating, and ventilation. A three hour per day lighting requirement was included in the 156 $kwh/m^2/y$ (14.5 kwh/sq ft/yr) building energy requirement.

Maintenance material costs include periodic repair of the booster pump, cleaning or replacement of the injector, and maintenance of the automatic switchover system. Labor is required for periodic changeover of the cylinders, and at least daily checking of the system operation and measurement of the chlorine residual. Daily labor requirements are assumed to average one-half hour per day.

Operation and maintenance requirements and costs are summarized in Table 95 and presented in Figures 81 and 82.

Typical Chemical Requirements and Costs

Table 96 presents chlorine costs for several different flow rates and dosages of 2, 5, and 8 mg/L. Annual costs for chlorine are based upon a cost of $272/metric ton ($300/ton). Several situations in Table 96 are listed as

"Not Applicable." These situations require chlorine delivery at rates which are less than the capacity of available chlorinators. Liquid hypochlorite solutions should be used for these low flow applications.

TABLE 94. CONSTRUCTION COST SUMMARY FOR GAS FEED CHLORINATION SYSTEMS

Cost Category	Chlorine Dose Up to 40 lb/day	40 to 80 lb/day
Excavation and Sitework	$ 1,200	$ 1,200
Manufactured Equipment	5,100	6,000
Concrete	300	300
Labor, Installation	600	600
Pipe and Valves	500	500
Electrical	2,100	2,100
Housing	7,800	7,800
Subtotal	17,600	18,500
Design Contingencies	2,600	2,800
Total	$20,200	$21,300

Note: Manufactured equipment category includes $500 for fan, damper and louvers which are not included in the basic building cost. Housing is a 10 ft by 10 ft building with a 10 ft height.

TABLE 95. OPERATION AND MAINTENANCE SUMMARY FOR GAS FEED CHLORINATION SYSTEMS

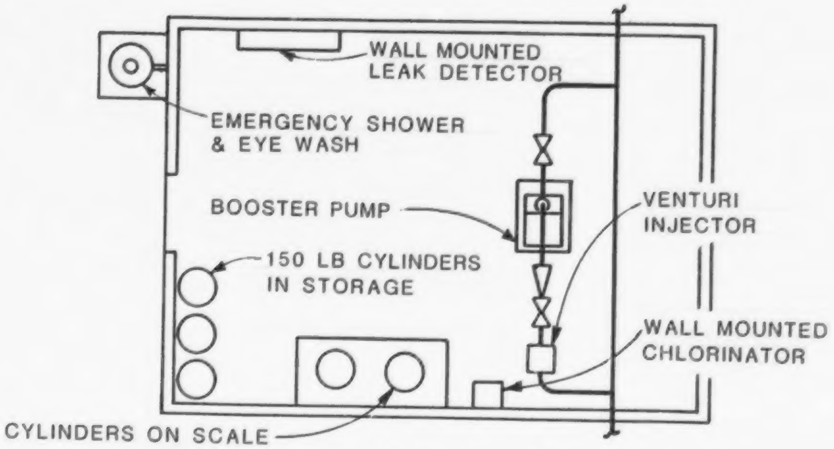
Chlorine Feed Capacity, lb/day	Energy, kwh/yr Building	Process	Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
<10	1,450	1,440	2,890	350	183	2,600
40	1,450	2,740	4,190	400	183	2,700
84	1,450	5,360	6,810	400	183	2,900

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

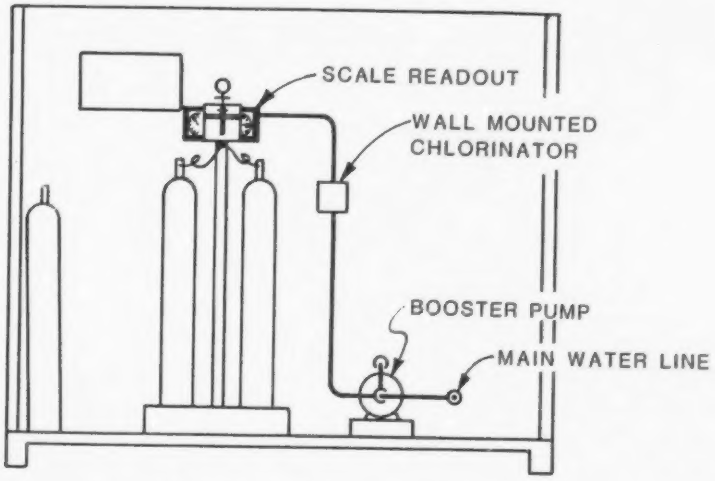
TABLE 96. TYPICAL CHEMICAL COSTS FOR GAS FEED CHLORINATION SYSTEMS

Average Plant Flow Rate, gpd	Annual Cost, $/yr		
	2 mg/L dosage	5 mg/L dosage	8 mg/L dosage
1,000	Not Applicable	Not Applicable	Not Applicable
10,000	Not Applicable	25	40
50,000	50	115	180
100,000	90	230	370
500,000	460	1,140	1,830
1,000,000	910	2,280	3,650

Notes: 1. Chlorine cost = $300/ton.
2. Situations shown as "Not Applicable" require chlorine flow rates less than the accurate metering capacity of chlorinators.


WALL MOUNTED
LEAK DETECTOR
EMERGENCY SHOWER
& EYE WASH
BOOSTER PUMP
VENTURI
INJECTOR
150 LB CYLINDERS
IN STORAGE
WALL MOUNTED
CHLORINATOR
CYLINDERS ON SCALE

PLAN VIEW


SCALE READOUT
WALL MOUNTED
CHLORINATOR
BOOSTER PUMP
MAIN WATER LINE

ELEVATION VIEW

Figure 79. Typical gas feed chlorination installation.

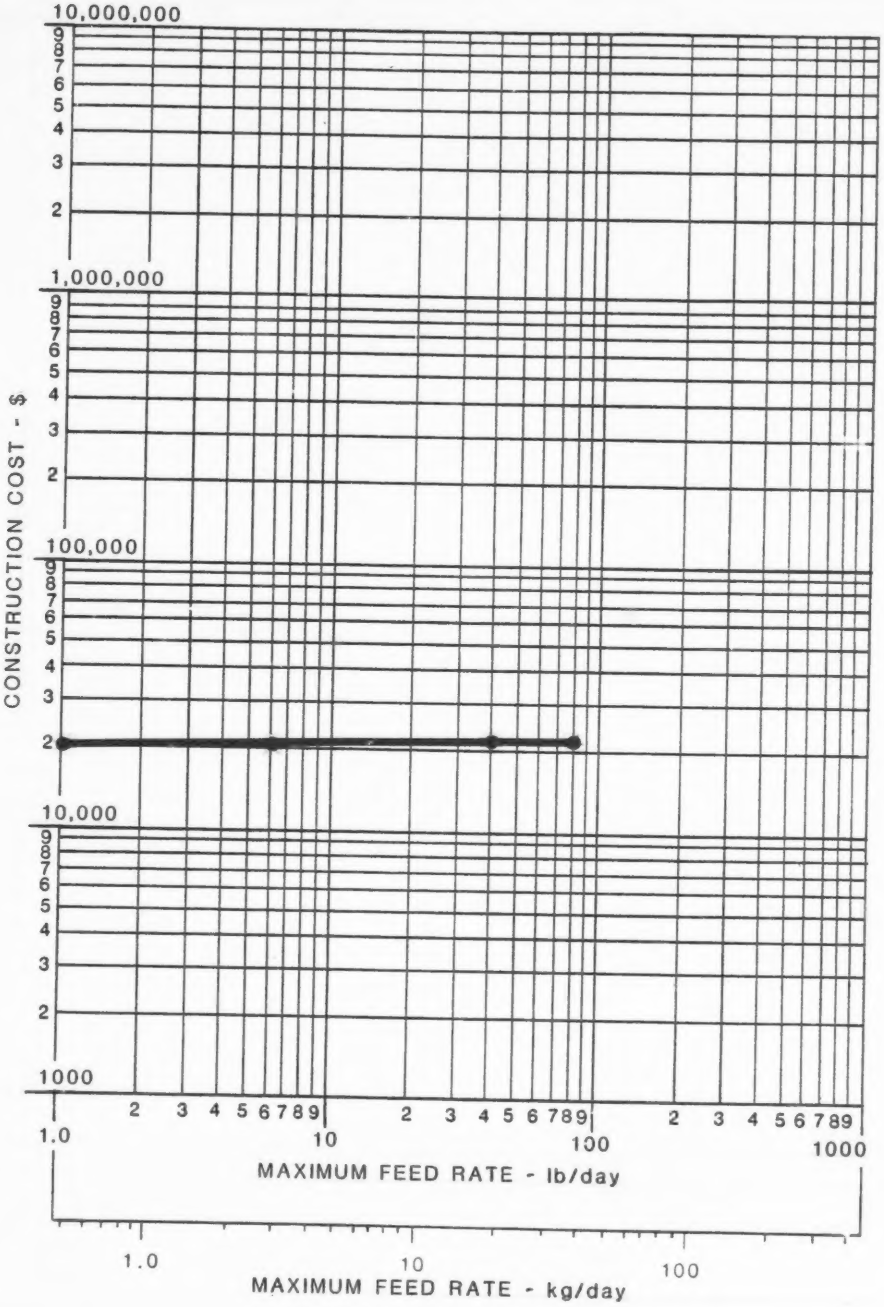


Figure 80. Construction cost for gas feed chlorination systems.

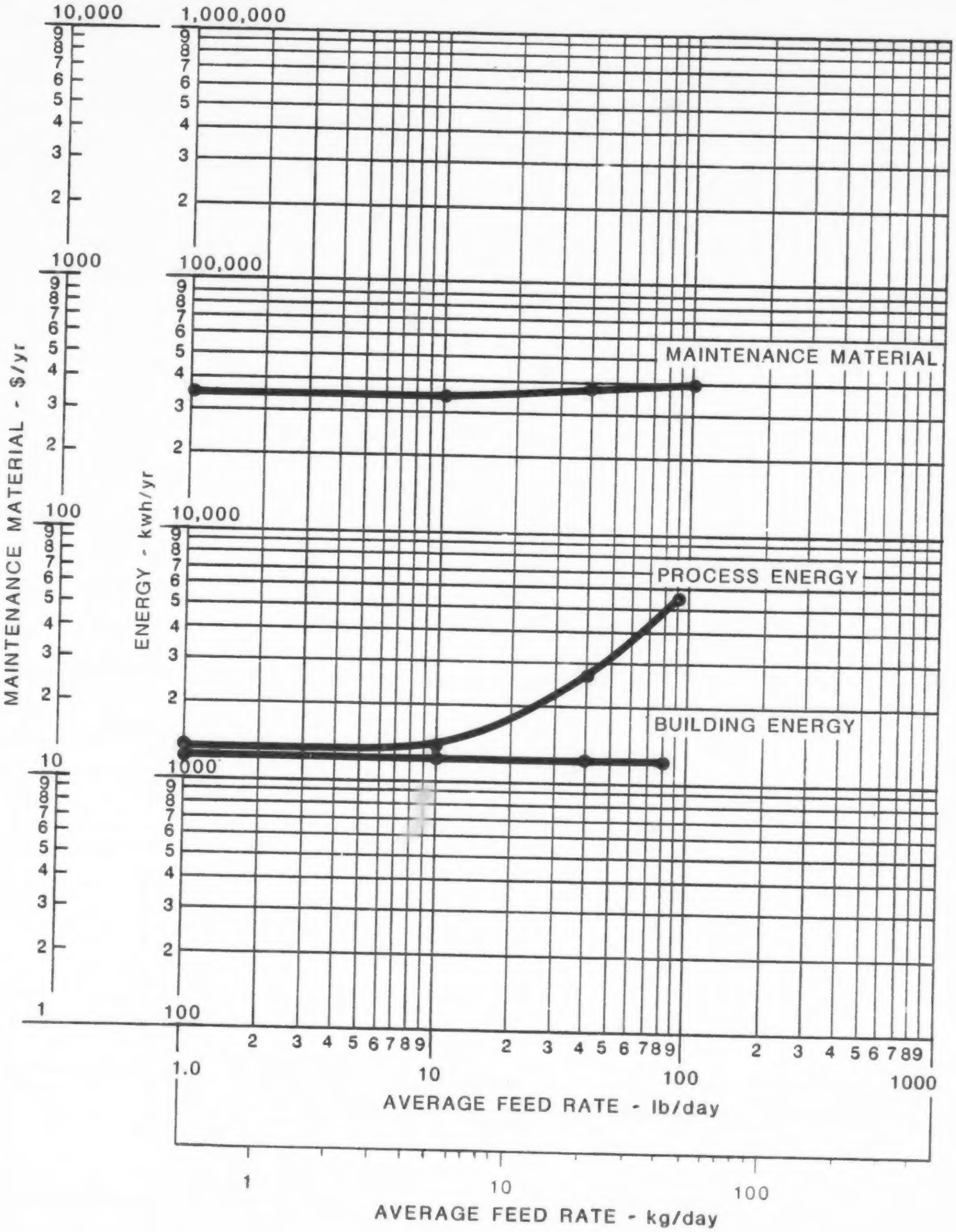


Figure 81. **Operation and maintenance requirements for gas feed chlorination systems - building energy, process energy, and maintenance material.**

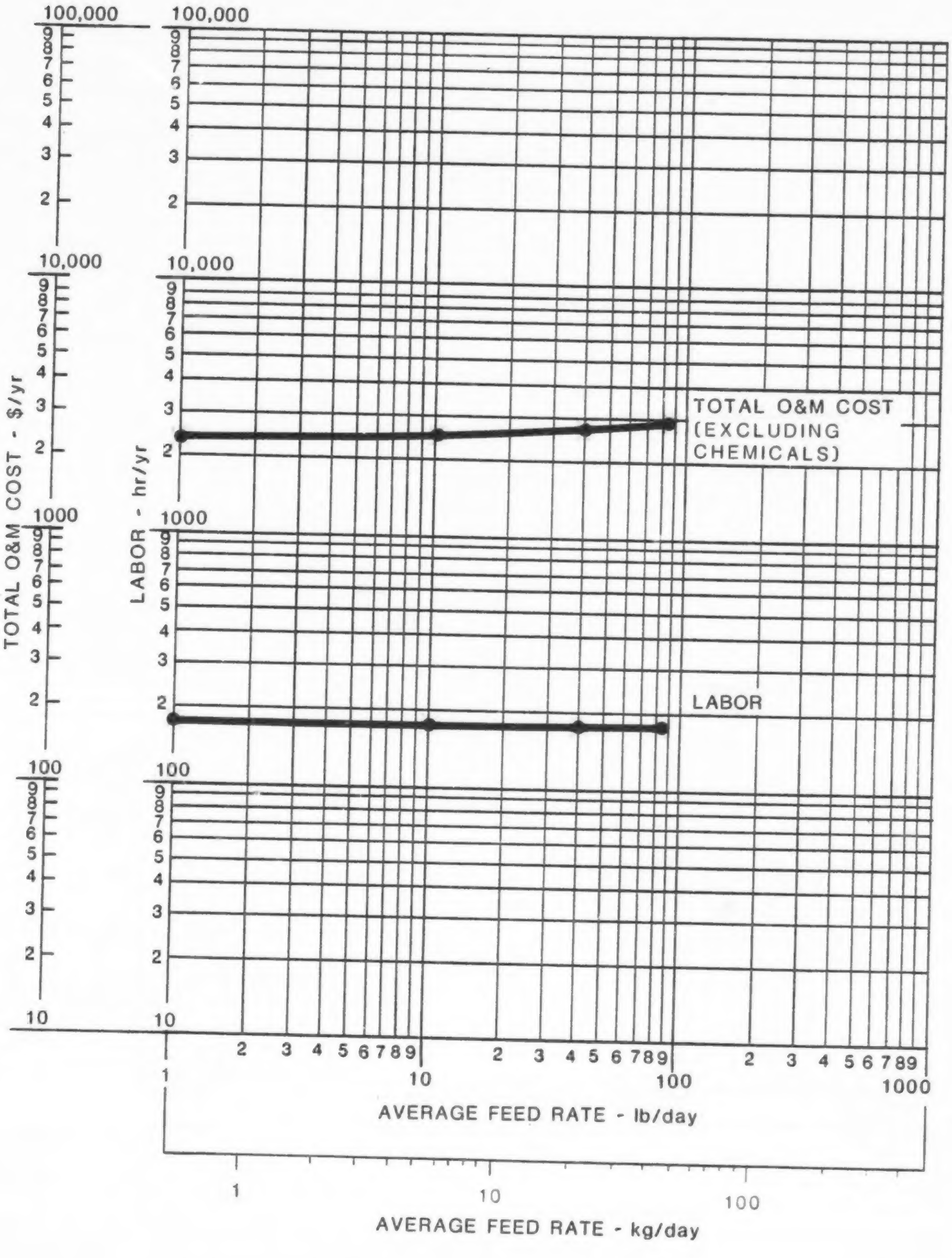


Figure 82. **Operation and maintenance requirements for gas feed chlorination systems - labor and total O&M cost.**

HYPOCHLORITE SOLUTION CHLORINATION SYSTEMS

Introduction

Many small utilities prefer to chlorinate using solutions of hypochlorite. The principal advantage of using hypochlorite solutions is elimination of the need to work with gaseous chlorine. Hypochlorite solutions can be prepared using either sodium hypochlorite [$NaOCl$] or calcium hypochlorite [$Ca(OCl)_2$]; both form hypochlorous acid in water according to the following equations.

$$NaOCl + H_2O \rightarrow HOCl + Na^+ + OH^-$$
$$Ca(OCl)_2 + H_2O \rightarrow 2HOCl + Ca^{++} + 2OH^-$$

In both chemicals, the active ingredient is the hypochlorite ion (OCl^-) which hydrolyzes to form hypochlorous acid ($HOCl$). The equilibrium between hypochlorous acid and hypochlorite ion is pH dependent with hypochlorous acid predominating at pH less than about 7.5. The only difference between the reactions of hypochlorites and gaseous chlorine in water is that hydroxide ion is produced when hypochlorites are used, and hydrogen ions are produced when gaseous chlorine is used.

Use of sodium hypochlorite is much more common than use of calcium hypochlorite, primarily due to safety hazards associated with calcium hypochlorite. Sodium hypochlorite is purchased as a 5 1/4% solution containing 0.053 kg/L (0.44 lb/gal) of available chlorine or as a 10% solution containing 0.1 kg/L (0.83 lb/gal) of available chlorine. Normally, the 10% solution is the concentration of choice. Although very stable, the rate of sodium hypochlorite deterioration increases at higher temperatures and concentrations. Liquid sodium hypochlorite can be purchased in 18.9 and 49.2 L (5 and 13 gal) carboys and in 113.6 L (30 gal) drums.

Calcium hypochlorite is purchased in a granular form, with approximately 65-70% available chlorine. The principal disadvantage of calcium hypochlorite is its safety hazard. During storage, it must not be subject to heating above 177°C (350°F), and it must not be allowed to come into contact with easily oxidizable organic material. If either of these conditions occur, decomposition can begin, releasing heat and generally causing a fire which releases chlorine monoxide and oxygen. Calcium hypochlorite in the granular form can be purchased in 2.2 kg (5 lb) cans, 45.4, 136 and 363 kg (100, 300, and 800 lb) drums, and 188 kg (415 lb) barrels. Drums and barrels are typically metal, although drums may be fiber drums which are specially lined. The solubility of granular calcium hypochlorite is about 0.22 kg/L (1.84 lb/gal).

Impact of Raw Water Quality on Treatment Cost

In addition to being disinfectants, the hypochlorous acid and hypochlorite ion which are formed by hypochlorite addition are both oxidants. Thus, the presence of oxidizable organics, oxidizable inorganics such as iron and manganese, or reducing compounds will increase the chlorine demand of the water, and therefore the cost of chlorination. To determine appropriate dosages, it is necessary to conduct chlorine demand tests on samples of the water to be disinfected.

Formation of trihalomethanes (THM) is another consideration which can affect cost. If THM precursors are present in the raw water, excessive concentrations of THM's (>0.1 mg/L) may be formed during treatment or in the distribution system. This may require a change in the type of treatment utilized, or a change in the point of chlorination. Such changes would likely affect treatment cost. Although changing treatment techniques would probably increase treatment cost, many large utilities which have moved the point of chlorination to after sedimentation have found that the change reduced the required chlorine dosage, and consequently the cost of chlorination.

Construction Costs

Although sodium hypochlorite is most commonly utilized, calcium hypochlorite may be applicable at higher feed rates. Construction costs have been developed for hypochlorite feed systems capable of feeding between 0.045 and 45.4 kg (0.1 to 100 lb) of chlorine per day. Basic components required for feeding hypochlorite solutions include: a solution tank with mixer for preparation and storage of dilute hypochlorite solution and a calibrated metering pump to pump solution from the solution tank to the injection point. Construction costs were developed using a 568 L (150 gal) solution tank equipped with a 0.25 kw (0.33 horsepower) mixer, and a 0.19 kw (0.25 horsepower) diaphragm metering pump with a maximum capacity of 265 L/d (70 gpd). The intake from the solution tank is equipped with a strainer to prevent plugging and/or damage to the metering pump.

Chlorine solution must only be fed when water is being produced, either by a treatment facility or by a well pump. The electrical control system included in the construction cost is designed with this feature. Output of the diaphragm metering pump must be set manually, and this will require a constant output from the well or treatment facility, in order to maintain a pre-established chlorine residual concentration.

All pipe and valves are PVC, which simplifies installation. Required housing is a building 3.05 by 3.05 m (10 by 10 ft) with a 3.05 m (10 ft) height. An emergency shower is provided within the building, and this shower is intended for use in the event of accidental operator contact with a high strength hypochlorite solution.

Construction costs are presented in Table 97 and Figure 83 for systems capable of feeding between 0.0045 and 454 kg/d (0.01 and 1,000 lb/day) of available chlorine as either sodium or calcium hypochlorite solution. Using this equipment, the available chlorine feed rate is a function of the hypochlorite solution strength and the established output of the metering pump.

Operation and Maintenance Requirements and Costs

Process electrical energy requirements are only for the diaphragm metering pump and the mixer on the hypochlorite solution tank, and consequently are relatively small. The diaphragm pump must operate continuously, assuming the treatment works is operating twenty-four hours per day, while the solution mixer is only operated for a short period of time during preparation of the hypochlorite solution.

TABLE 97. CONSTRUCTION COST SUMMARY FOR HYPOCHLORITE SOLUTION CHLORINATION SYSTEMS

Cost Category	Cost
Excavation and Sitework	$ 1,200
Manufactured Equipment	2,700
Concrete	300
Labor	400
Pipe and Valves	500
Electrical	2,200
Housing	7,800
Subtotal	15,100
Design Contingencies	2,300
Total	$17,400

Note: The facilities are suitable for delivering up to 100 lb/day of available chlorine.

Building electrical requirements for heating, ventilating, and lighting are calculated based on 156 kwh/m^2/y (14.5 kwh/sq ft/yr). This figure is based upon lighting the building only during routine operation and maintenance functions. Three hours of lighting per day were assumed.

Operational labor required is for preparation of the hypochlorite solution, daily checking of the equipment and mixer operation, and measurement of the chlorine residual. An average of one-half hour per day is used in the calculations. This amount of time would be sufficient for preparation of a solution from either liquid sodium hypochlorite or granular calcium hypochlorite. Maintenance labor is minimal, and would be only for metering pump maintenance.

Maintenance materials are for periodic replacement of diaphragms in the metering pump, and miscellaneous items related to this metering pump. Operation and maintenance requirements are summarized in Table 98 and in Figures 84 and 85.

Typical Chemical Requirements and Costs

Table 99 presents typical costs for use of 10% sodium hypochlorite at dosages of 2, 5, and 8 mg/L. These costs are based upon a cost of $0.23/L ($0.88/gal) for 10% sodium hypochlorite solution.

TABLE 98. OPERATION AND MAINTENANCE SUMMARY FOR HYPOCHLORITE SOLUTION CHLORINATION SYSTEMS

Cost Category	Requirement
Energy	
Building	1,450 kwh/yr
Process	1,750 kwh/yr
Total	3,200 kwh/yr
Maintenance Material	$ 350/yr
Labor	180 hr/yr
Total Cost	$2,600/yr

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 99. TYPICAL CHEMICAL COSTS FOR HYPOCHLORITE SOLUTION CHLORINATION SYSTEMS

Average Plant Flow Rate, gpd	Annual Cost, $/yr		
	2 mg/L dosage	5 mg/L dosage	8 mg/L dosage
1,000	7	17	27
10,000	70	170	270
50,000	340	600	1,340
100,000	670	1,670	2,680
500,000	3,350	8,370	13,400
1,000,000	6,700	16,740	26,790

Note: Costs are based upon use of 10% sodium hypochlorite at a cost of $0.88/gal, which is equal to $1.10/lb of free available chlorine.

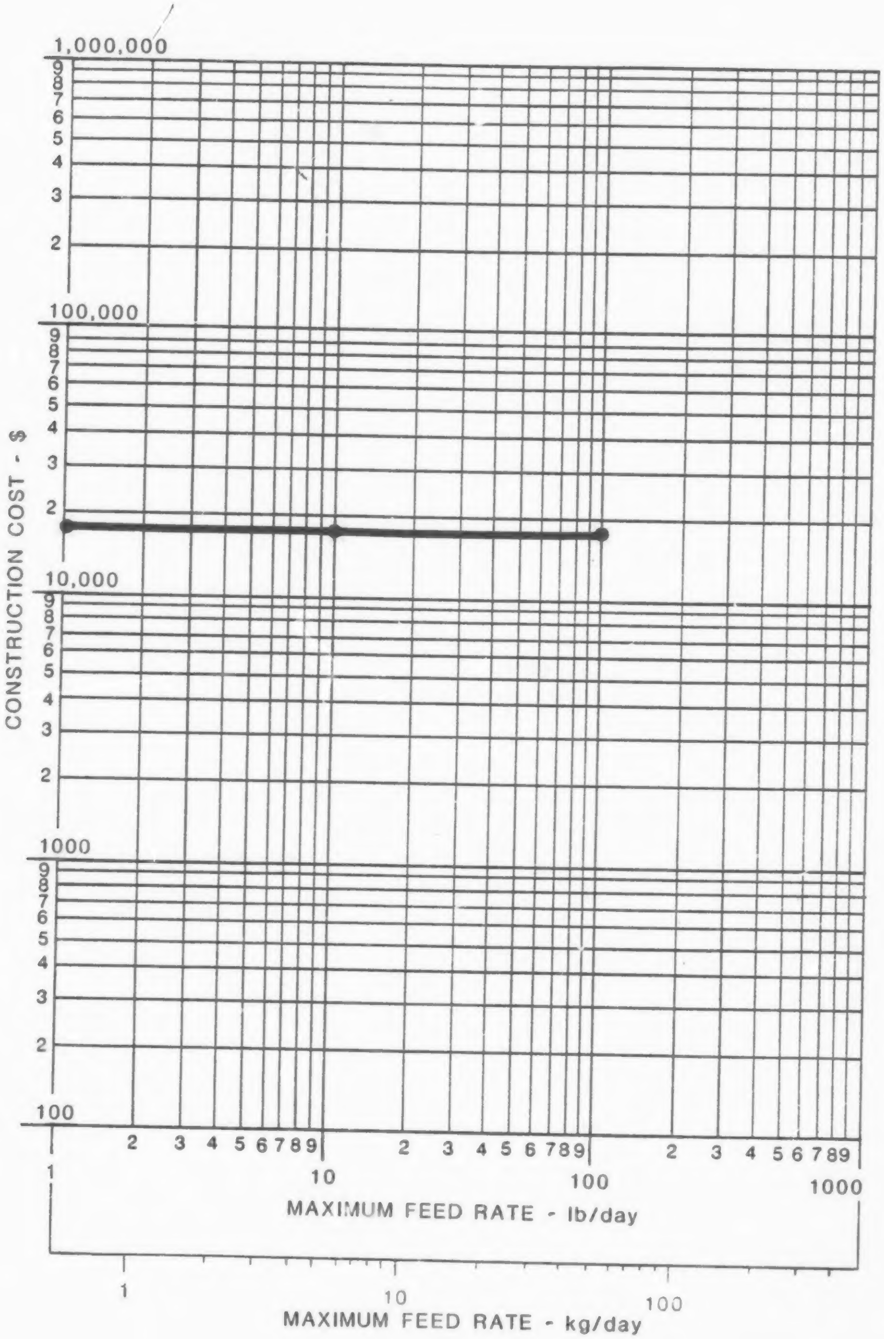


Figure 83. Construction cost for hypochlorite solution chlorination systems.

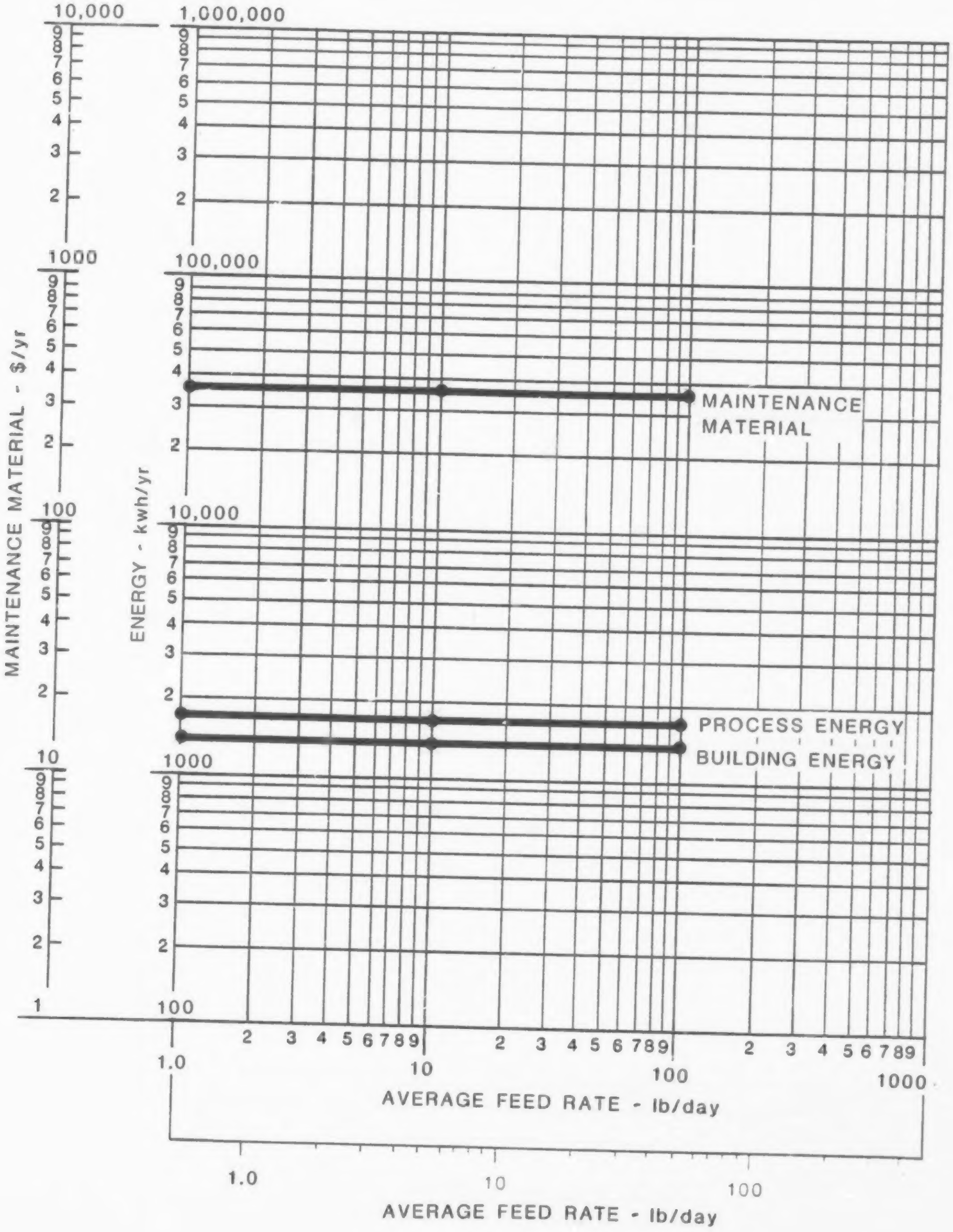


Figure 84. **Operation and maintenance requirements for hypochlorite solution chlorination systems - building energy, process energy, and maintenance material.**

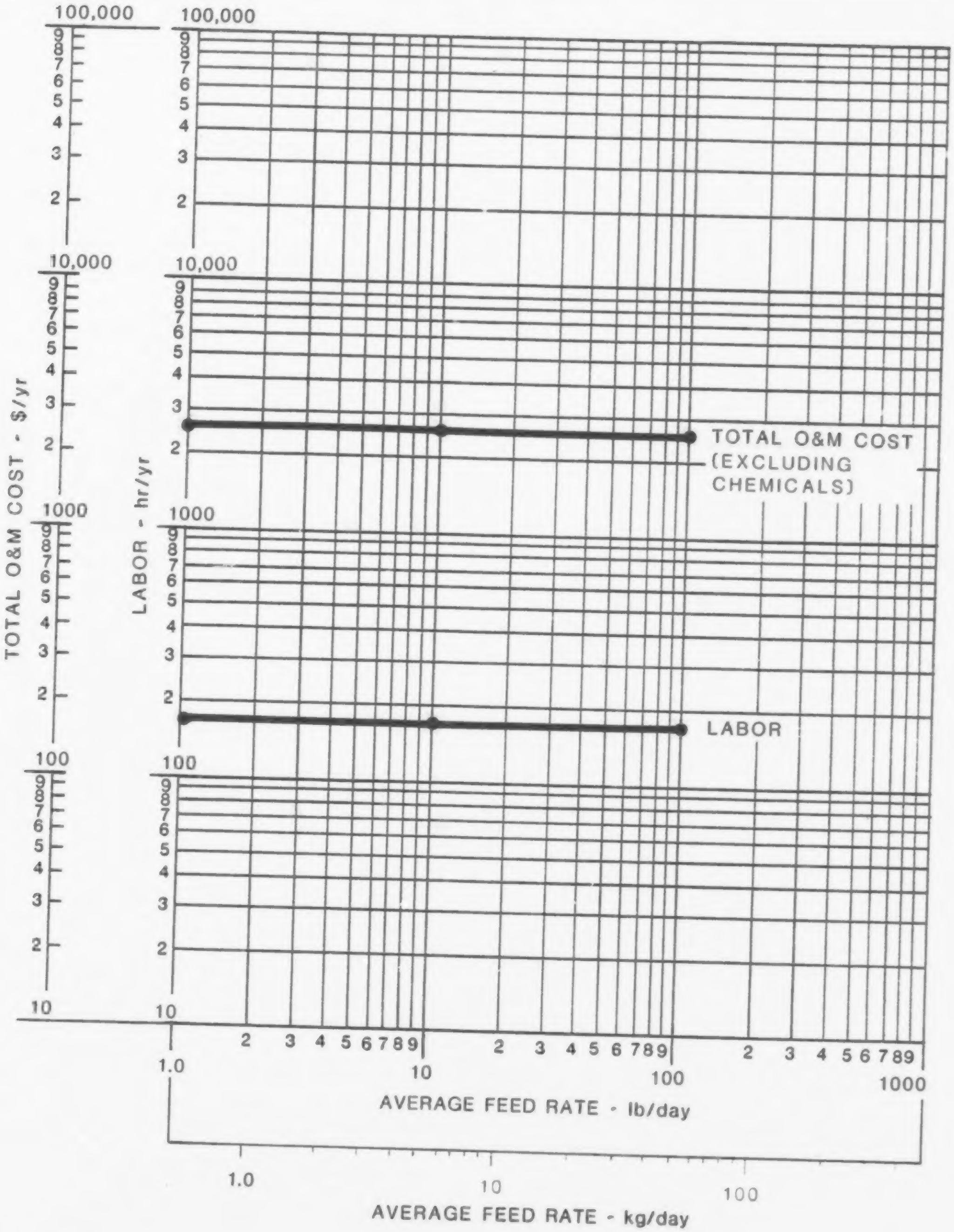


Figure 85. **Operation and maintenance requirements for hypochlorite solution chlorination systems - labor and total O&M cost.**

PELLET FEED CHLORINATORS

Introduction

The primary use of pellet feed chlorinators is automatic chlorination of small well supplies. The chlorinator is rigidly mounted next to the well, with either a floor mount to a permanent foundation or a casing mount directly to the well casing. The chlorinator feeds dry chlorine pellets at an adjustable rate through a plastic pellet tube directly into the well casing. Chlorinator operation is simultaneous with operation of the well pump. Dry, EPA approved chlorine pellets containing 70% available chlorine as calcium hypochlorite and weighing 1 gram (0.03 oz) each are available from the chlorinator manufacturer (Land-O-Matic Chlorinator, Autotrol Corporation).

The chlorinator delivers chlorine pellets only when the well pump is running, and provides continuous chlorination of the water well and pump system for the control of iron bacteria, hydrogen sulfide, and the slimes they produce, as well as providing a chlorine residual in a storage tank or reservoir. Chlorination ahead of the well screen and pump is beneficial because it will eliminate the possibility of fouling by iron bacteria. The chlorinator has been marketed for small municipal or rural utilities with a well water supply, as well as for both farm and home well water supplies. The chlorinator is constructed to be weather resistant, and does not require a special housing. However, housing may be desirable or necessary from the standpoint of vandalism. In general, the pellet feed chlorinator is easier to operate than either gas chlorinators or hypochlorite solution feeders, although it requires relatively frequent pellet replacement at high feed rates.

The pellet feed chlorinator also has application for chlorinating water from a surface supply as it flows into a storage reservoir. In this application, the unit would be mounted on the cover of the reservoir, and would feed chlorine pellets through the cover into a plastic basket which is submerged in the inlet line to the tank. The manufacturer recommends that the pellet be immersed in flowing water in order to dissolve at a somewhat controlled rate. This application of the pellet feed chlorinator would require special plumbing since it is not a standard application.

The pellet feed chlorinator has a pellet feed rate of up to 8.64 kg of pellets/day (19 lb/day) which is equivalent to 6.05 kg/d (13.3 lb/day) of available chlorine. This rate is adequate for chlorinating a well delivering 12.62 L/s (200 gpm) at a chlorine dosage of over 5.5 mg/L. If higher feed rates are required, a high speed motor is available which will allow feed rates up to 18.2 kg of chlorine/day (40 lb/day).

Construction Costs

Construction costs for pellet feed chlorinator installations include the chlorinator, mounting pipe and well casing bracket, electrical wiring and connection to the well pump control, and installation labor. Construction costs are summarized in Table 100 and Figure 86. At feed rates above 1.36 kg (3 lb) of chlorine per day, abrasion of the pellets increases, and the pellet housing must be removed and cleaned about twice a year. A spare pellet housing

TABLE 100. CONSTRUCTION COST SUMMARY FOR PELLET FEED CHLORINATORS

Cost Category	Cost
Manufactured Equipment	$ 790
Labor, Installation	150
Electrical	60
Subtotal	1,000
Design Contingencies	150
Total	$1,150

Note: These costs are applicable for chlorine feed rates up to 6.05 kg/d (13.3 lb/day); however, the manufacturer recommends that a spare pellet housing be purchased for systems using above 1.36 kg/d (3 lb/day) of chlorine. The cost of a spare pellet housing is $125. A high speed motor which can deliver up to 18.2 kg/d (40 lb/day) of chlorine is available for an additional cost of $25.

is recommended if continuous chlorine feed is required while the housing is being cleaned.

Operation and Maintenance Requirements and Costs

Operation requirements for pellet feed chlorination of wells include keeping the pellet storage housing supplied with pellets meeting the specifications required for the chlorinator, periodic inspections, and periodic checking of the chlorine residual. The chlorinator has a pellet storage capacity of 6.8 kg (15 lb).

Labor for inspection of the unit and occasional checking of chlorine residual is assumed to be 1 hour per week for all feed rates. Labor for filling the chlorinator with the chlorine pellets was included at 0.5 hours per fill. Electrical requirements are for the drive motor and indicator light on the chlorinator. Maintenance materials include occasional replacement of gaskets, the indicator light, clutch springs, and replacement of the drive motor after 10,000 hours of operation. Operation and maintenance requirements are summarized in Table 101, and are shown in Figures 87 and 88.

TABLE 101. OPERATION AND MAINTENANCE SUMMARY FOR PELLET FEED CHLORINATORS

Chlorine Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.1	2	20	54	600
0.5	8	20	61	700
1	17	20	70	800
2	35	35	87	1,000
5	85	50	139	1,600
10	171	75	227	2,600
13	228	90	284	3,200

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

Pellets can only be purchased from the chlorinator manufacturer, and in October 1983 the list price was $129 for 15.9 kg (35 lb) of pellets. These pellets contain 70% available chlorine as calcium hypochlorite. Following are chemical costs for several feed rates.

Chlorine Feed Rate, lb/day	Chlorine Cost, $/yr
0.1	190
1	1,920
5	9,610
10	19,220
13	24,980

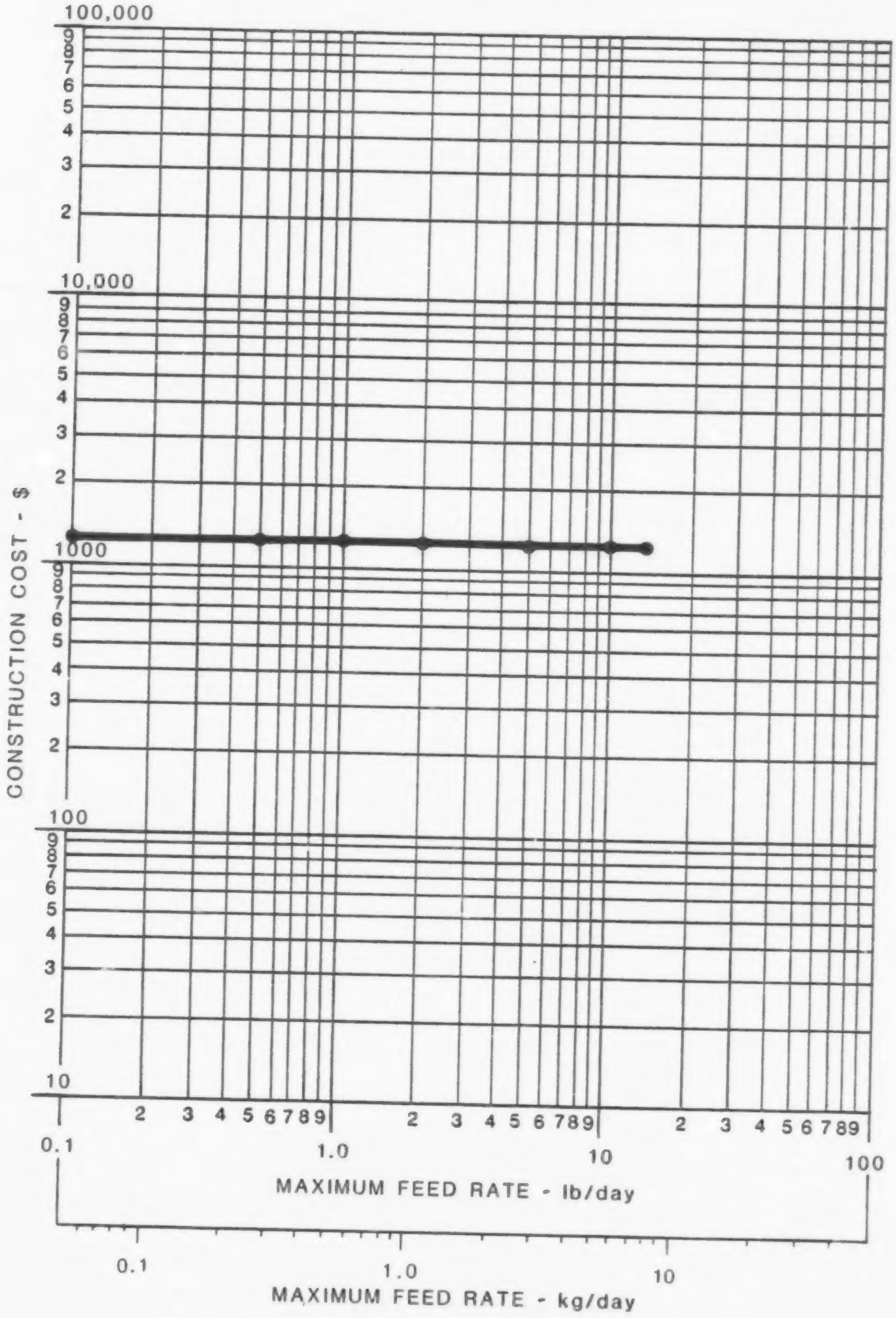


Figure 86. Construction cost for pellet feed chlorinators.

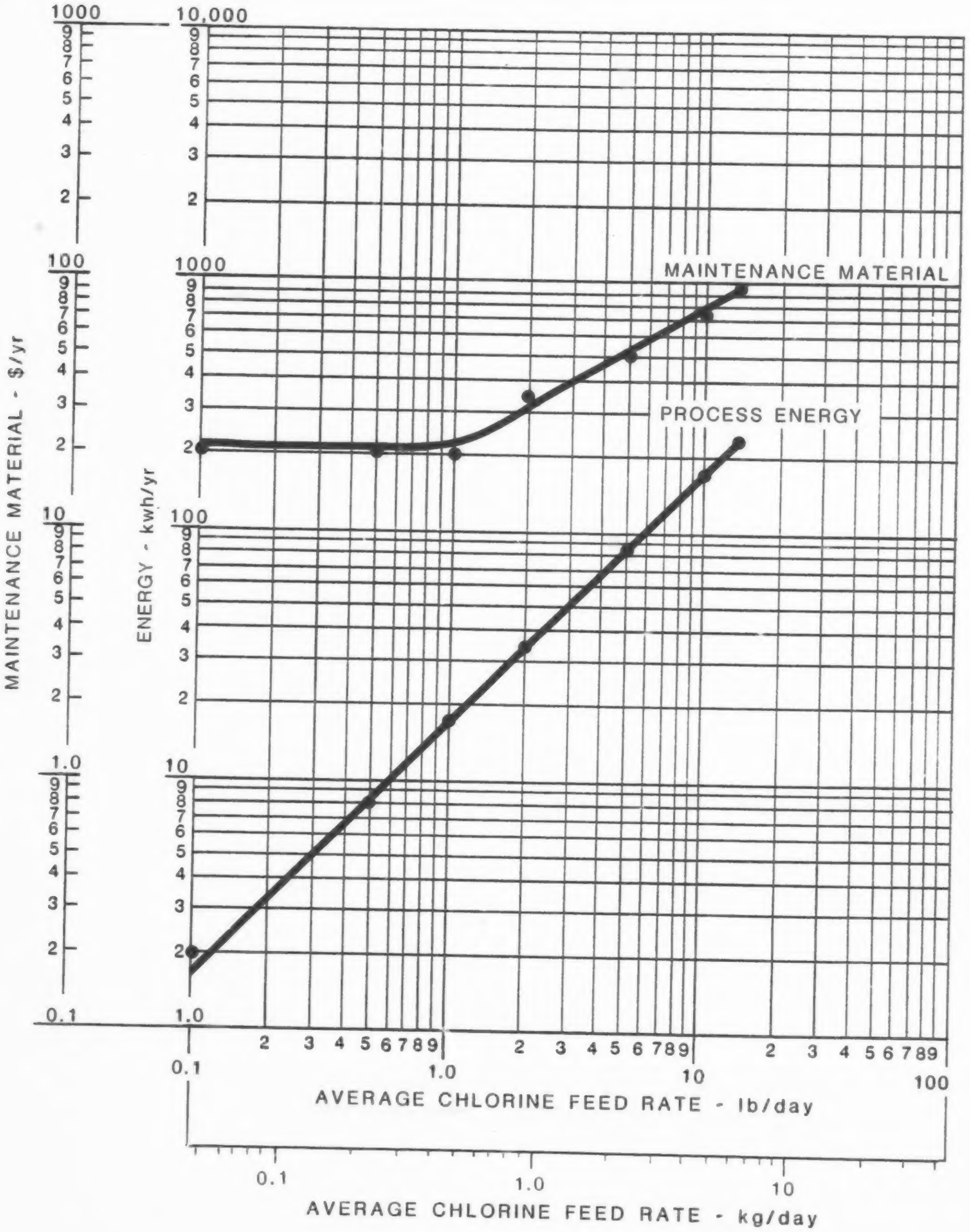


Figure 87. **Operation and maintenance requirements for pellet feed chlorinators - process energy and maintenance material.**

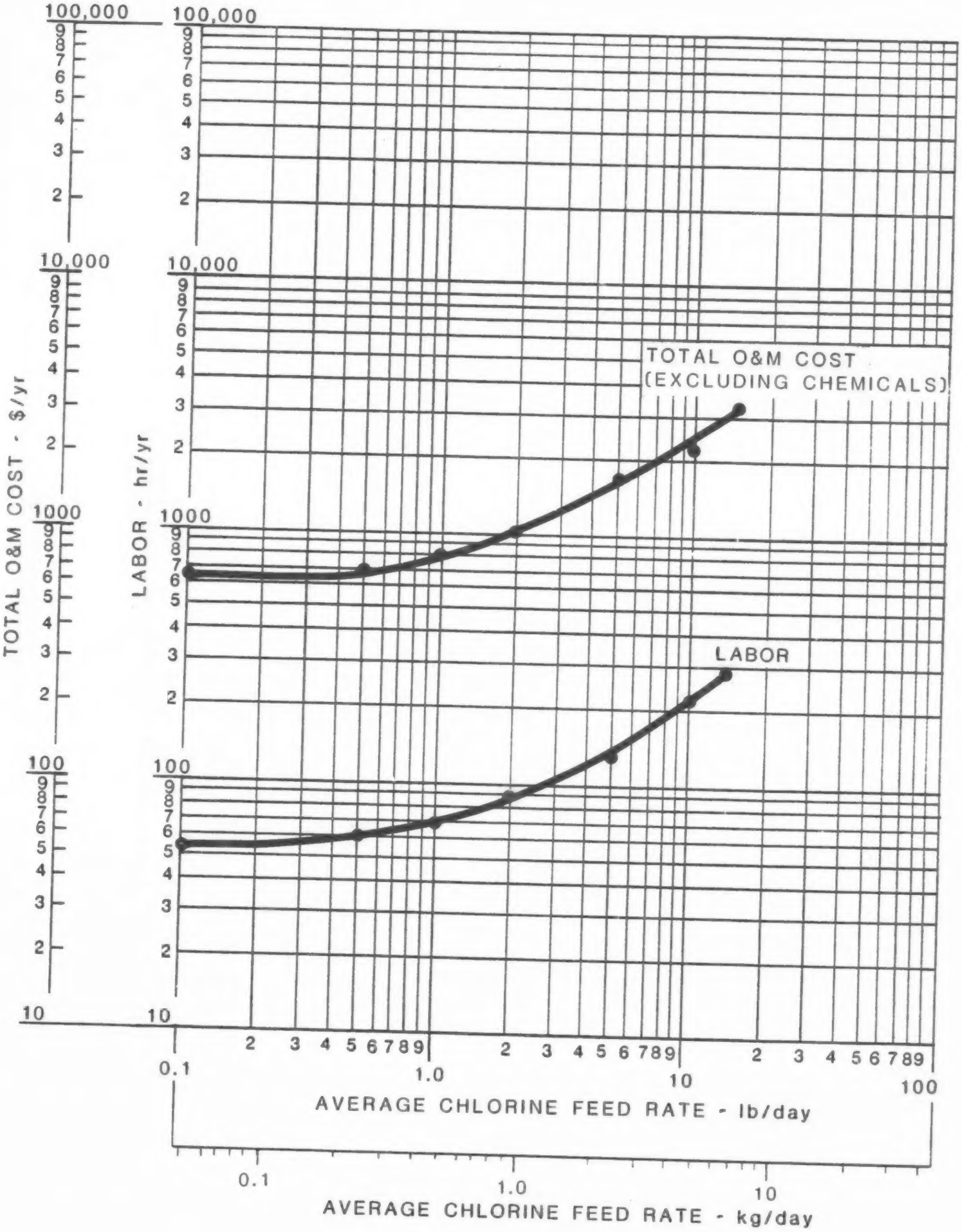


Figure 88. Operation and maintenance requirements for pellet feed chlorinators - labor and total O&M cost.

EROSION FEED CHLORINATORS

Introduction

The operating principle of erosion feed chlorinators is erosion of calcium hypochlorite tablets at a controlled rate. The tablets contain about 70% available chlorine as calcium hypochlorite and weigh about 57 gm (2 oz) each. The unit is installed so that water flows either by gravity or under pressure to the chlorinator and, after passing through the chlorinator, falls by gravity into a hypochlorite solution tank or directly to the point of application. The chlorinator consists of a refillable hopper which stores the hypochlorite tablets and immerses them in a dissolving chamber. Water rises up through the perforated bottom of the hopper and slowly dissolves the tablets. The rate that the tablets dissolve is controlled by the depth that the hopper is lowered into the dissolving chamber, which controls the quantity of hypochlorite pellets immersed in water, and the rate of water flow through the chlorinator. Erosion feed chlorinators are marketed by Water-Sure, Inc. under the trade name Water-Sure.

A nonelectric gravity operated feeder (Water-Sure Model 101) is available for chlorination of supplies delivered by pressure pipeline to a contact tank or storage reservoir. The pressure pipeline may be from either a well pump or a storage reservoir at a higher elevation. The chlorinator and a flow control valve are installed within or immediately over the contact tank or reservoir, so that after the water supply flows through the flow control valve and the chlorinator, it falls by gravity into the reservoir or contact tank. The flow control valve is operated by a float within the reservoir, and automatically controls water flow through the chlorinator and maintains the reservoir water level. The unit will treat from 0.19 to 378.5 m^3/d (50 to 100,000 gal/day).

Two other chlorinators are available for use in pressurized water systems. Both chlorinators include a solution tank to store hypochlorite solution, with subsequent injection of the hypochlorite solution into the pressure water supply line. A float mechanism controls the level in the hypochlorite solution storage tank, and thus the water flow through the chlorinator.

One of these pressure system chlorinators (Water-Sure Model 151) is designed to chlorinate pressure systems which use an above ground pump. This chlorinator is connected to the high pressure line from the pump discharge through a pressure reducing valve. The chlorinator produces a high strength hypochlorite solution, which is then stored in a solution tank. The hypochlorite solution is added to a bypass line which is installed from the high pressure discharge side of the pump to the suction side of the pump. A manually operated valve is used to control the rate of flow through the bypass line, and a Venturi injector is used to create a vacuum which draws hypochlorite solution from the storage tank into the bypass line. The rate of chlorine addition is controlled by the manually operated valve on the bypass line (which controls the rate of flow through the injector and hence, the injector vacuum) and the depth that the chlorine tablet hopper is lowered into the chlorinator dissolving chamber (which controls the concentration of the hypochlorite solution which is produced).

A second pressure system chlorinator (Water-Sure Model 152) is specifically designed to chlorinate directly into a pressure water supply line using a chemical feed pump to inject the hypochlorite solution. This chlorination system is used when the well pump is not accessible, such as with a submersible pump. A pressure reducing valve reduces the line pressure to provide water for the chlorinator, which produces a high strength hypochlorite solution. A chemical feed pump draws suction from the hypochlorite storage tank and feeds it under pressure into the pressure water line.

Both chlorination units applicable to pressure systems can treat from 0.19 to 473.1 m^3/d (50 to 125,000 gal/day).

Construction Costs

Construction costs for the three chlorinator models are summarized in Table 102 and Figure 89.

TABLE 102. CONSTRUCTION COST SUMMARY FOR EROSION FEED CHLORINATORS

Cost Category	Gravity Operated Feeder	Pressurized Water Systems	
	Chlorinator Mounted Above Storage Tank	Venturi Injector for Chlorine Addition. For Above Ground Pump.	Chemical Feed Pump for Chlorine Addition. For Submersible Well Pump.
Manufactured Equipment	$ 700	$ 790	$ 850
Pipe and Valves	50	100	100
Labor, Installation	100	200	200
Electrical	--	--	50
Housing	--	--	100
Subtotal	$ 850	$1,090	$1,300
Design Contingencies	130	165	195
Total	$ 980	$1,255	$1,495

The gravity operated chlorination system includes the chlorinator unit, float mechanism system and flow control valve, delivery hose with fittings, hand valve and "Y" strainer. The unit can be mounted on a bracket attached to the chlorine contact tank (or reservoir) wall or on a rigid piece of pipe on the inlet side of the unit. A removable cover over the unit is necessary so that the tablet storage hopper can be refilled on a regular basis. No cost is included for this removable cover, as it is site-specific and may exist in many potential installations.

The two chlorinators which are used in pressurized water systems include the chlorinator unit, float mechanism, hand valve and injector, pressure reducing valve, 83.3 L (22 gal) hypochlorite storage tank, 1.8 m (6 ft) of solution feed line, and the chemical feed pump (Model 152 only). It is assumed that the unit designed for use with an above ground pump would be enclosed in the same housing as the pump. A housing is included in the construction cost estimate for the chlorinator and the chemical feed pump used for injection into a pressurized water line.

Operation and Maintenance Requirements and Costs

Labor for inspection of the unit and checking of the chlorine residual is included at one hour per week. Labor for filling the chlorinator with the calcium hypochlorite tablets is included at 0.5 hours per fill. The tablet storage hopper holds only 1.14 kg (2.5 lb) of tablets, and for high chlorine feed rates, the labor requirement becomes substantial. Maintenance material requirements include (1) replacing the strainer and occasionally the diaphragm in the flow control valve in Water-Sure Model 101; (2) repair to the Venturi injector and occasional replacement of the solution feed tubing in Water-Sure Model 151; and (3) repairs to the chemical feed pump and occasional replacement of the solution feed tubing in Water-Sure Model 152.

Electrical energy is only required for the chemical feed pump in Water-Sure Model 152, which is designed to operate by injecting hypochlorite solution directly into a pressure water supply line.

Operation and maintenance requirements are summarized in Table 103 and are presented in Figures 90 and 91.

TABLE 103. OPERATION AND MAINTENANCE SUMMARY FOR EROSION FEED CHLORINATORS

Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr	
				Without Electrical	With Electrical
0.1	22	10	62	690	690
0.5	108	12	104	1,200	1,200
1	216	14	156	1,700	1,700
2	433	16	260	2,900	2,900
4	867	18	469	5,200	5,200
6	1,300	20	678	7,500	7,600

Notes: 1. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.
2. Electrical energy only applies to Water-Sure Model 152, which uses a liquid hypochlorite feed pump.

Typical Chemical Requirements and Costs

The calcium hypochlorite tablets have a December 1983 price ranging from \$2.86 to \$3.52 per kg (\$1.30 to \$1.60 per lb). The tablets are manufactured by Olin and are marketed as HTH (high test hypochlorite) containing 70% available chlorine. These tablets have been approved by EPA for drinking water chlorination and are available from the manufacturer and from swimming pool suppliers.

Typical chemical costs based upon a tablet cost of \$3.52/kg (\$1.60/lb) and 70% available chlorine are shown following:

Chlorine Feed Rate, lb/day	Chlorine Cost, \$/yr
0.1	85
1.0	835
2	1,670
4	3,340
6	5,010
8	6,675

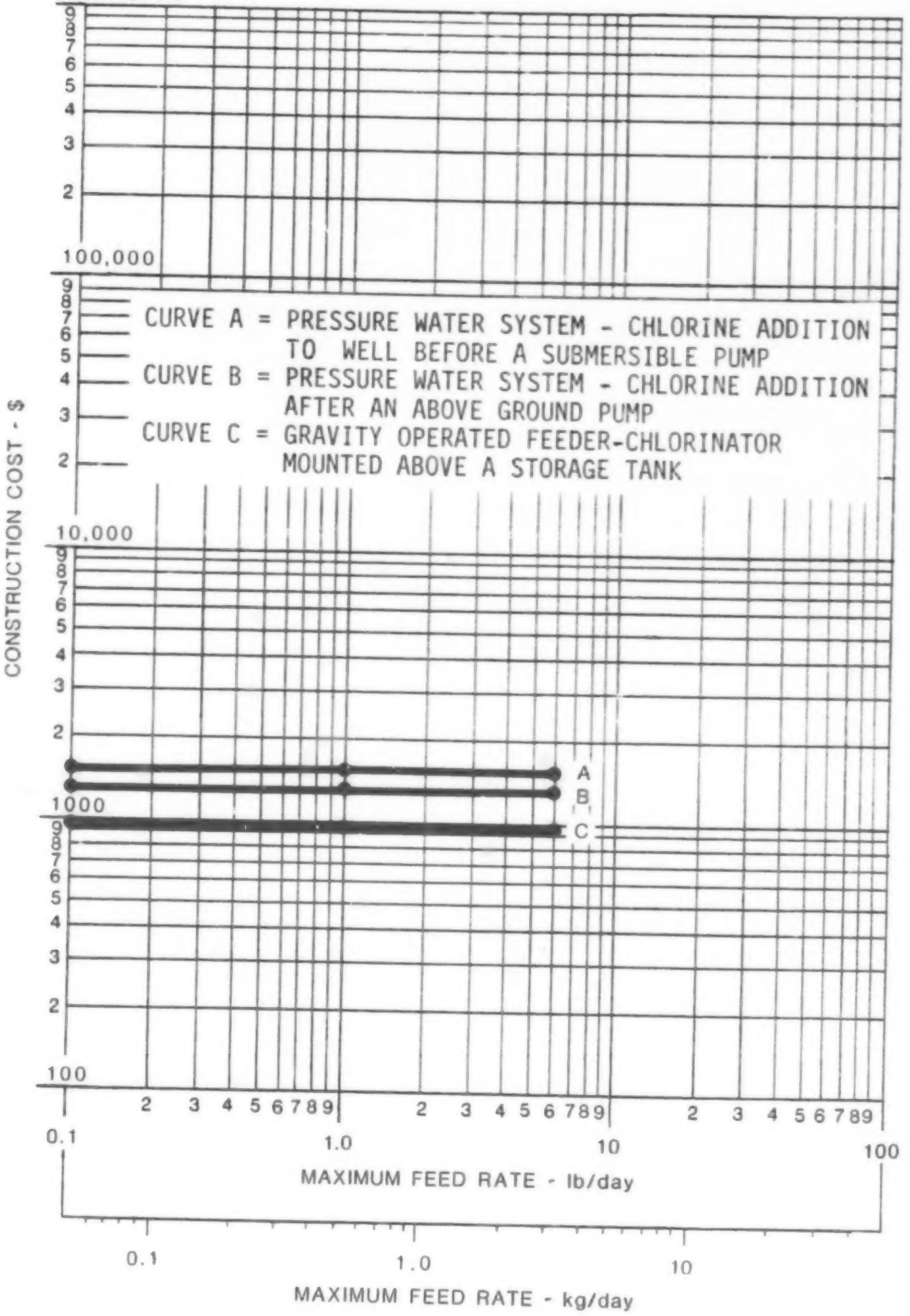


Figure 89. Construction cost for erosion feed chlorinators.

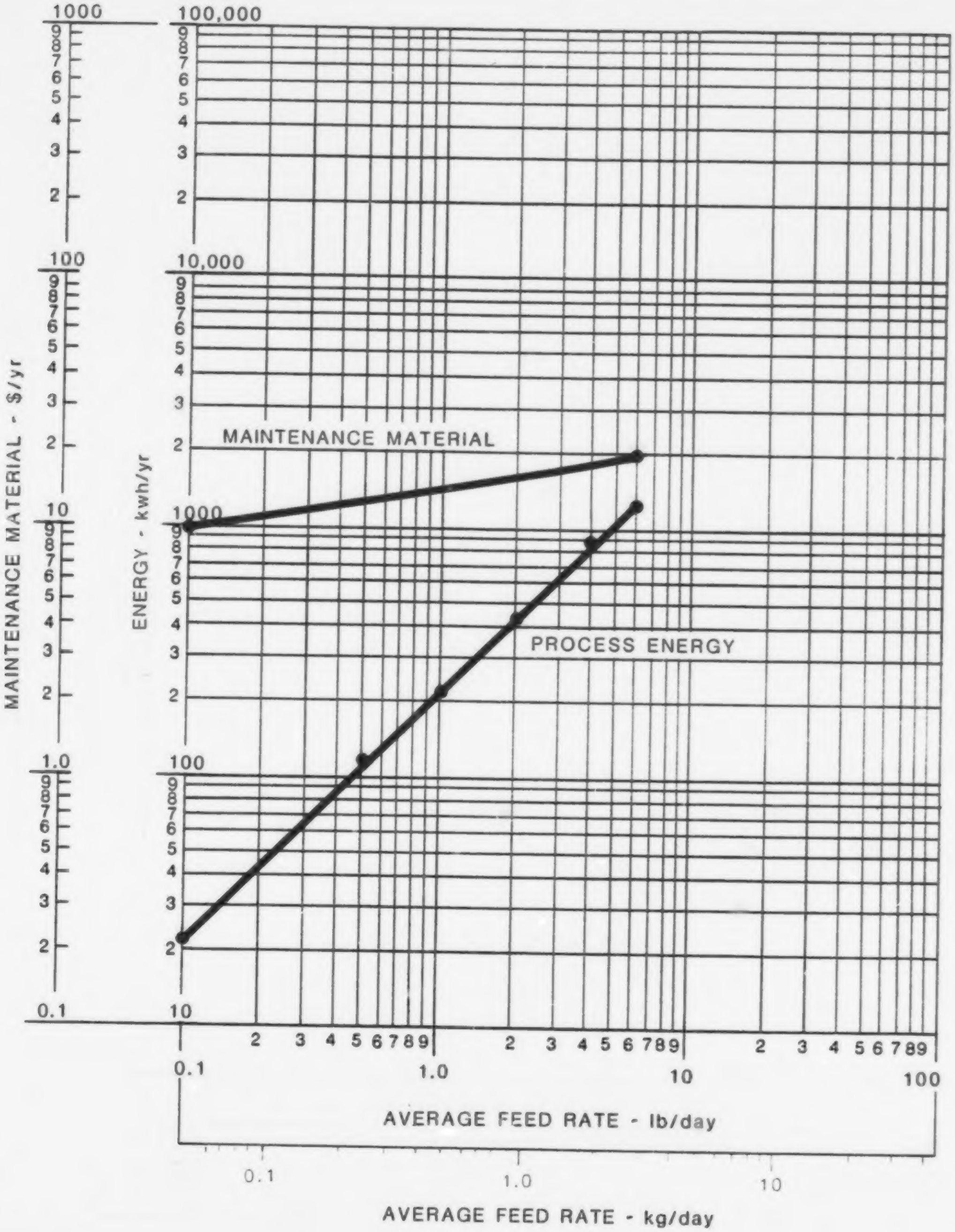


Figure 90. **Operation and maintenance requirements for erosion feed chlorinators - process energy and maintenance material.**

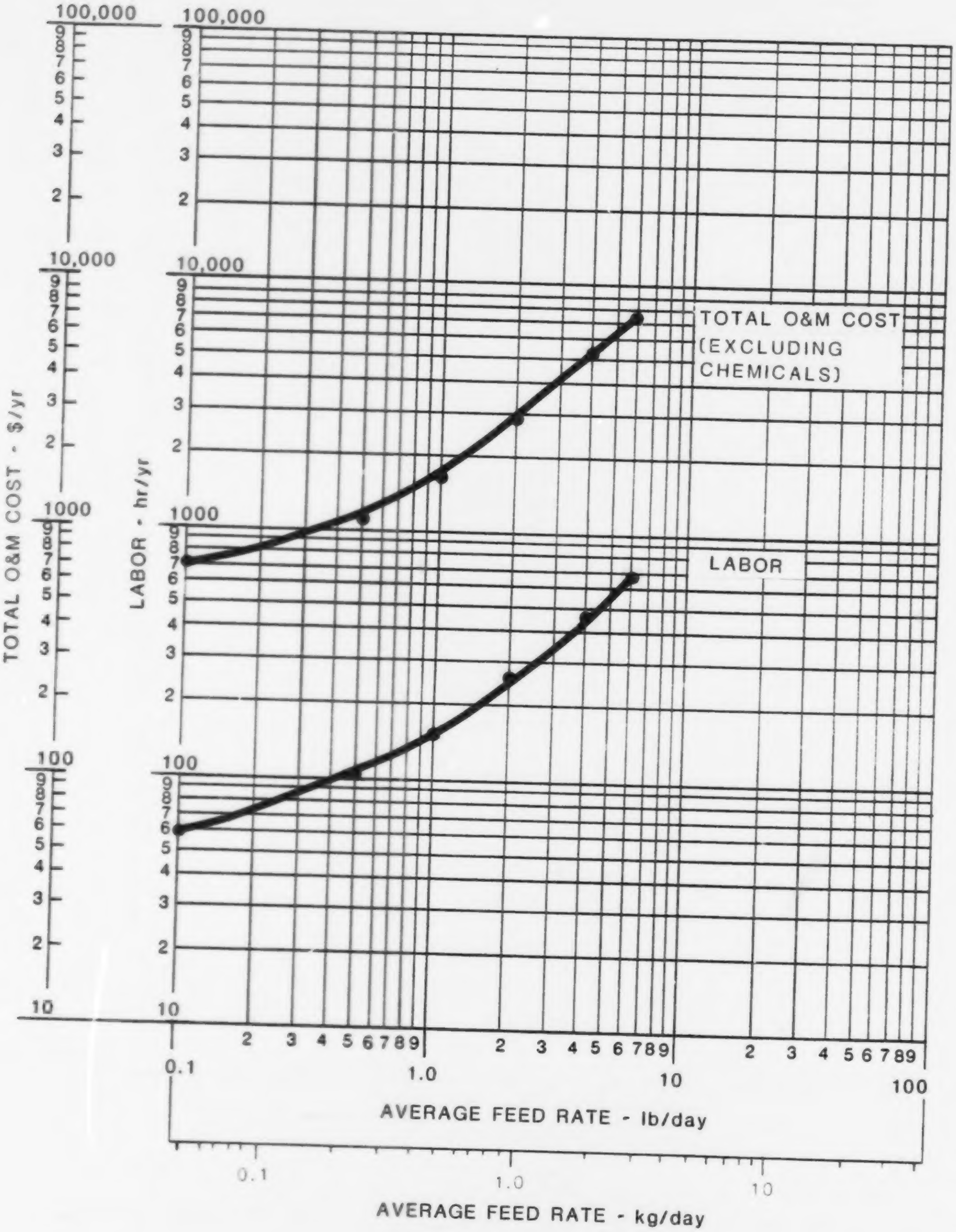


Figure 91. **Operation and maintenance requirements for erosion feed chlorinators - labor and total O&M cost.**

ON-SITE HYPOCHLORITE GENERATION SYSTEMS

Introduction

When sodium hypochlorite is used for disinfection, an alternative to purchasing sodium hypochlorite is to utilize sodium hypochlorite solution generated on-site. Sodium hypochlorite can be produced in an electrolytic cell using purified salt, softened water, and electrical energy. Salt is dissolved in the softened water to form a concentrated brine solution, which is diluted and passed through the electrolytic cell. Electrolysis takes place according to the following equation:

$$NaCl + H_2O \rightarrow NaOCl + H_2 \text{ (gas)}$$

The sodium hypochlorite solution which is produced contains 9,000 mg/L NaOCl and about 20,000 mg/L of unreacted salt; therefore, for every mg/L of sodium hypochlorite used for disinfection, 2.2 mg/L of sodium chloride is also added.

A water softener is normally required, since cleaning requirements for the electrolytic cell are minimized when the total hardness of the water used for brine make-up is less than 30 mg/L. Use of purified salt is essential.

Hydrogen gas is also produced during the electrolysis reaction, and can be a safety hazard if improperly handled. The recommended approach is to vent hydrogen gas from both the electrolytic cell and the hypochlorite storage tank to a remote location where there is no chance for accidental combustion.

Construction Costs

Construction costs for the on-site hypochlorite generation system are summarized in Table 104 and Figure 93, for systems with capacities ranging from 9 to 45 kg per day (20 to 100 lb/day) of chlorine equivalent (Note: 0.45 kg (1 lb) Cl_2 is equivalent to 0.48 kg (1.05 lb) of sodium hypochlorite). The cost for manufactured equipment is for a pre-packaged, skid-mounted unit. The

TABLE 104. CONSTRUCTION COSTS FOR ON-SITE HYPOCHLORITE GENERATION SYSTEMS

	Maximum Generation Rate, lb/day of Chlorine Equivalent		
Cost Category	<20	50	100
Manfactured Equipment	$13,100	$16,700	$20,800
Pipe and Valves	300	400	400
Labor, Installation	1,200	1,400	1,900
Electrical, Instrumentation	300	300	500
Housing	6,100	7,000	8,200
Subtotal	21,000	25,800	31,800
Design Contingencies	3,200	3,900	4,800
Total	$24,200	$29,700	$36,600

manufactured equipment includes a water softener; a salt storage/brine dissolution tank and brine dilution control system; a brine transfer system; an electrolytic cell with a ruthenium dioxide anode and titanium cathode; a transformer rectifier control panel; interconnecting piping, all assembled and skid-mounted with the equipment; a float-type level switch for incorporation with a hypochlorite storage tank; and a hydrogen blower required to vent hydrogen from the hypochlorite storage tank.

No costs are included for the hypochlorite storage tank or hypochlorite pumping, since these costs are presented in a separate section titled "Hypochlorite Solution Chlorination Systems." These costs must be added to the costs presented in this section to obtain the costs for a complete system.

The salt storage/brine dissolution tank has salt storage capacities of 15, 6, and 5 days for the 9, 23, and 45 kg/d (20, 50, and 100 lb/day) systems respectively. Pipe and valve costs include an allowance for 1.9 cm (3/4 in) water supply line, 1.3 to 5.1 cm (1/2 to 2 in) hypochlorite transfer line, 5.1 cm (2 in) hydrogen vent lines, and 5.1 cm (2 in) drain line. Electrical and instrumentation costs include electrical conduit and wiring required for hookup of 110 volt, single phase power for the 9 kg/d (20 lb/day) system, 220 volt, 3 phase power for the 23 kg/d (50 lb/day) system and 440 volt, 3 phase power for the 45 kg/d (100 lb/day) system. Housing costs are based upon including the equipment in a larger building housing other equipment, rather than a separate building specifically for the hypochlorite generation equipment. A typical installation is shown in Figure 92.

Operation and Maintenance Requirements and Costs

Energy requirements for on-site hypochlorite generation are about 5.5 kwh/kg (2.5 kwh/lb) of equivalent chlorine. Electrical energy for lighting, heating, and ventilating is included under building energy.

The largest maintenance material requirement is for anode replacement. For estimating purposes, it was assumed that the anodes were replaced every two years. Other material requirements are for miscellaneous parts associated with the electrolysis cells, for periodic regeneration of the cation exchange resin, and for nitric or muriatic acid required every three months for cleaning the electrolysis cells.

Labor requirements include labor for delivery and handling of bagged salt, operation of electrolysis cells, cleaning of electrolysis cells, electrode replacing, and regeneration of the cation exchange softening resin. Operation and maintenance requirements are summarized in Table 105 and are presented in Figures 94 and 95.

Typical Chemical Requirements and Costs

Chemical costs associated with production of hypochlorite solution in the electrolysis cell are principally for purified salt, but also must include acid for cleaning the cell. Typical chemical costs are presented in Table 106, based upon a salt requirement for the electrolysis cell of 3.5 kg/kg (3.5 lb/lb) of chlorine equivalent produced and a purfied salt cost of $0.11 kg ($0.05/lb).

TABLE 105. OPERATION AND MAINTENANCE SUMMARY FOR ON-SITE HYPOCHLORITE GENERATION SYSTEMS

Average Hypochlorite Generation Rate, lb/day of Chlorine Equivalent	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
1	1,800	900	2,700	300	30	800
6	1,800	5,500	7,300	500	50	1,600
20	1,800	18,200	20,000	800	150	3,900
50	2,000	45,600	47,600	1,500	260	7,700
100	2,400	91,200	93,600	2,100	440	13,500

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

TABLE 106. TYPICAL CHEMICAL COSTS FOR ON-SITE HYPOCHLORITE GENERATION SYSTEMS

Average Hypochlorite Generation Rate, lb/day of Chlorine Equivalent	Salt Cost, $/yr	Acid Cost, $/yr	Total Cost, $/yr
1	60	50	110
6	380	50	430
20	1,280	50	1,330
50	3,200	100	3,300
100	6,400	100	6,500

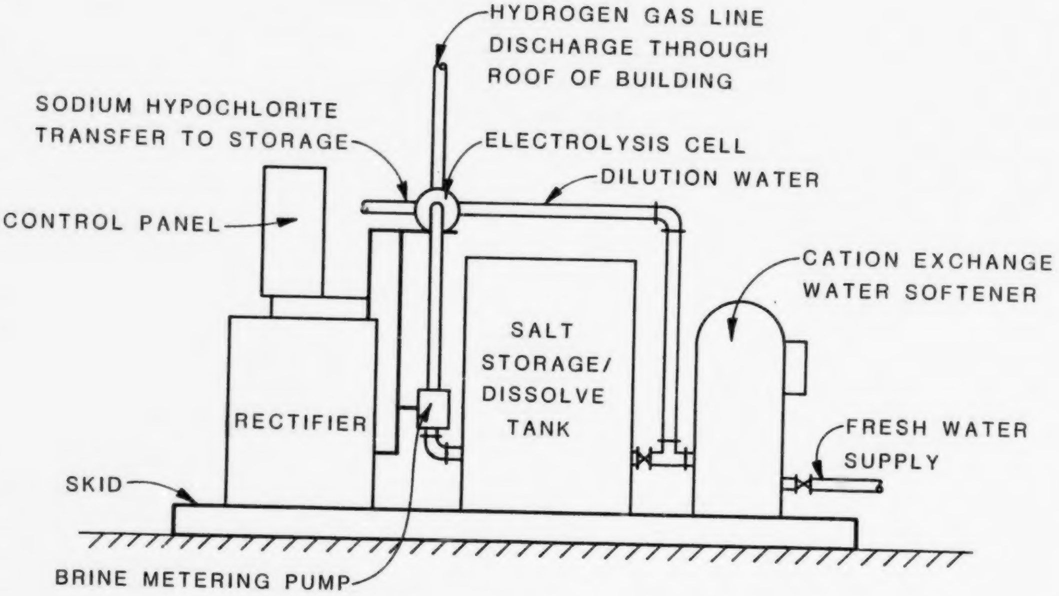

HYDROGEN GAS LINE
DISCHARGE THROUGH
ROOF OF BUILDING
SODIUM HYPOCHLORITE
TRANSFER TO STORAGE
ELECTROLYSIS CELL
DILUTION WATER
CONTROL PANEL
CATION EXCHANGE
WATER SOFTENER
SALT
STORAGE/
DISSOLVE
TANK
RECTIFIER
FRESH WATER
SUPPLY
SKID
BRINE METERING PUMP

Figure 92. **Typical skid-mounted on-site hypochlorite generation system installation.**

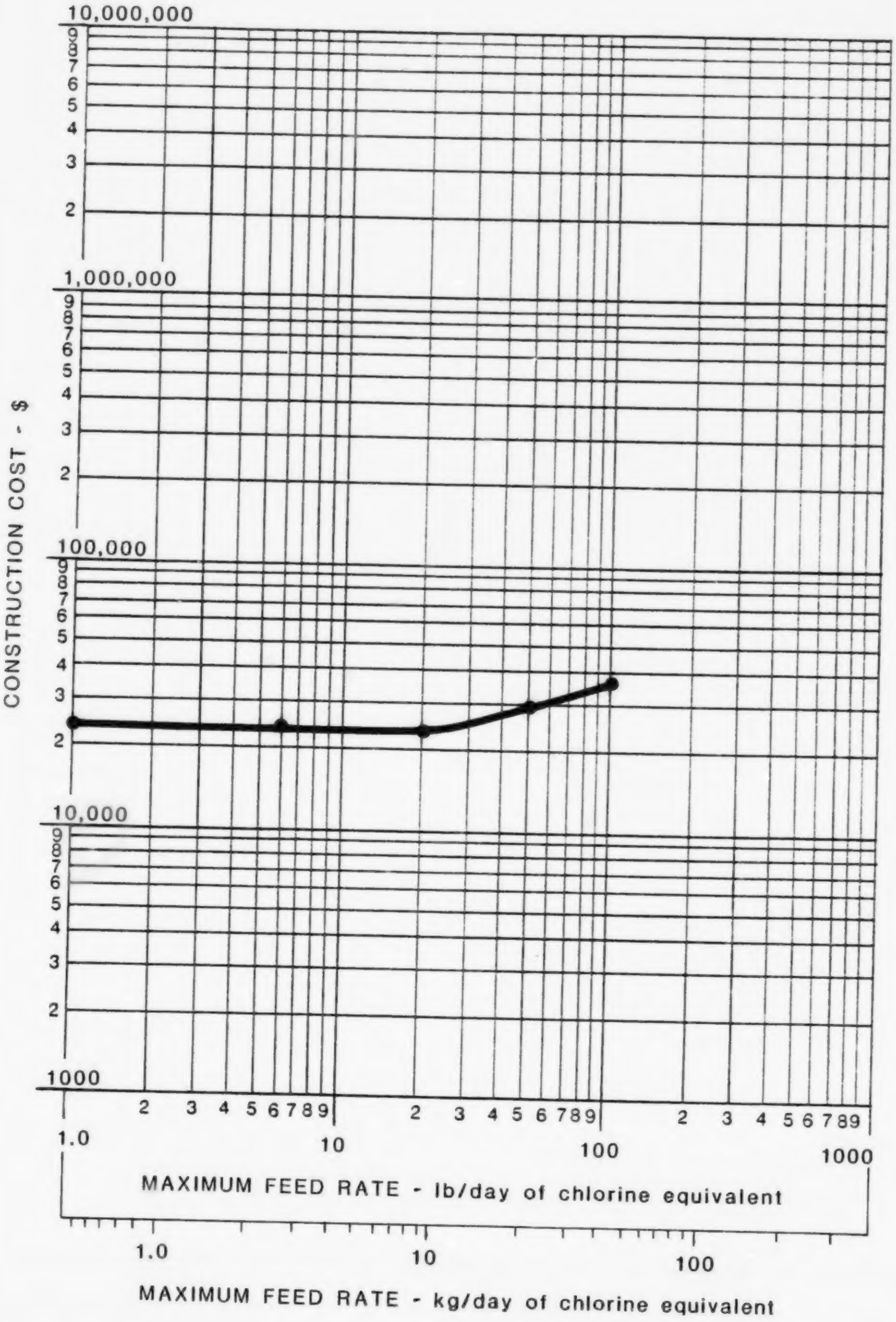


Figure 93. **Construction cost for on-site hypochlorite generation systems.**

13-A

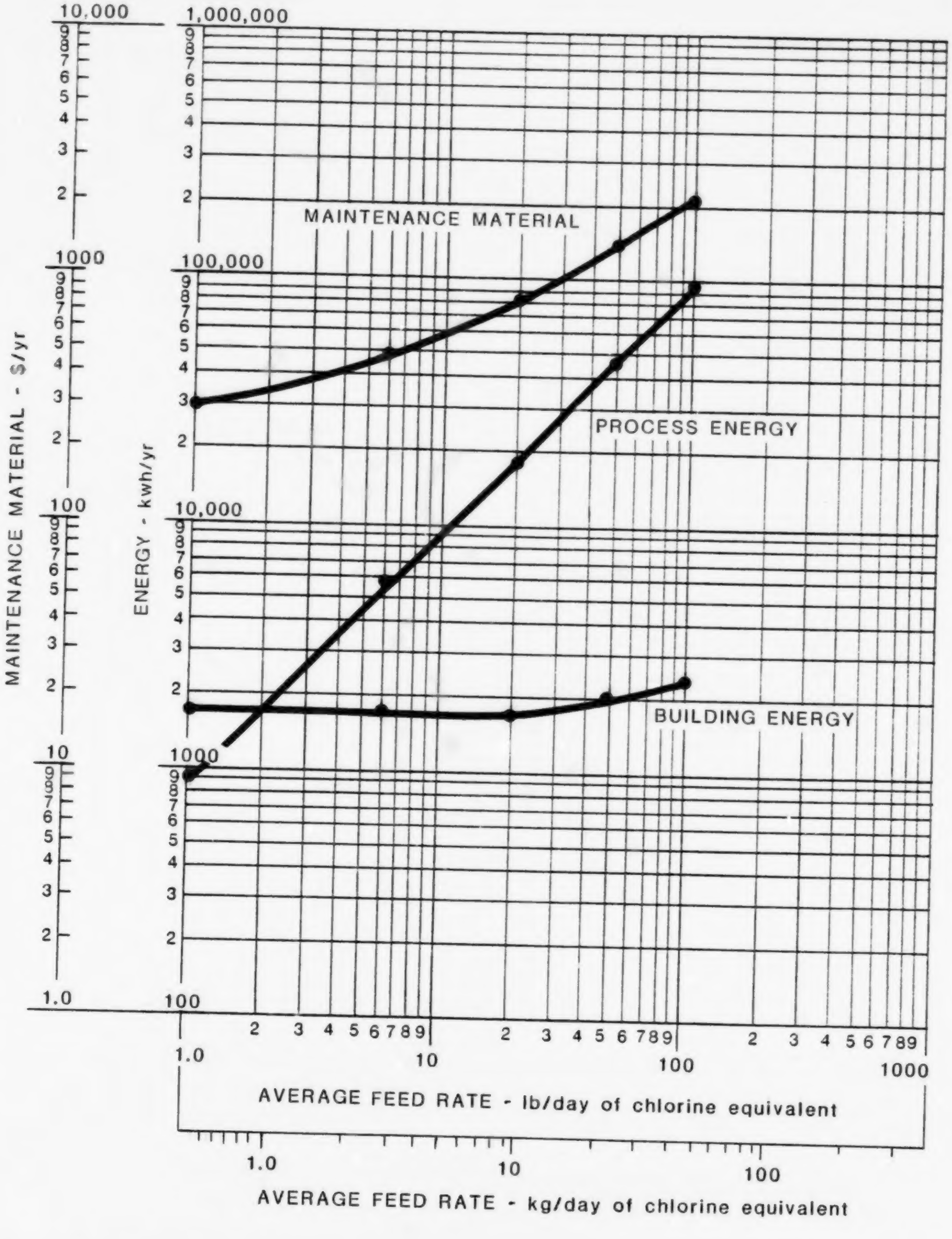


Figure 94. **Operation and maintenance requirements for on-site hypochlorite generation systems - building energy, process energy, and maintenance material.**

45-1

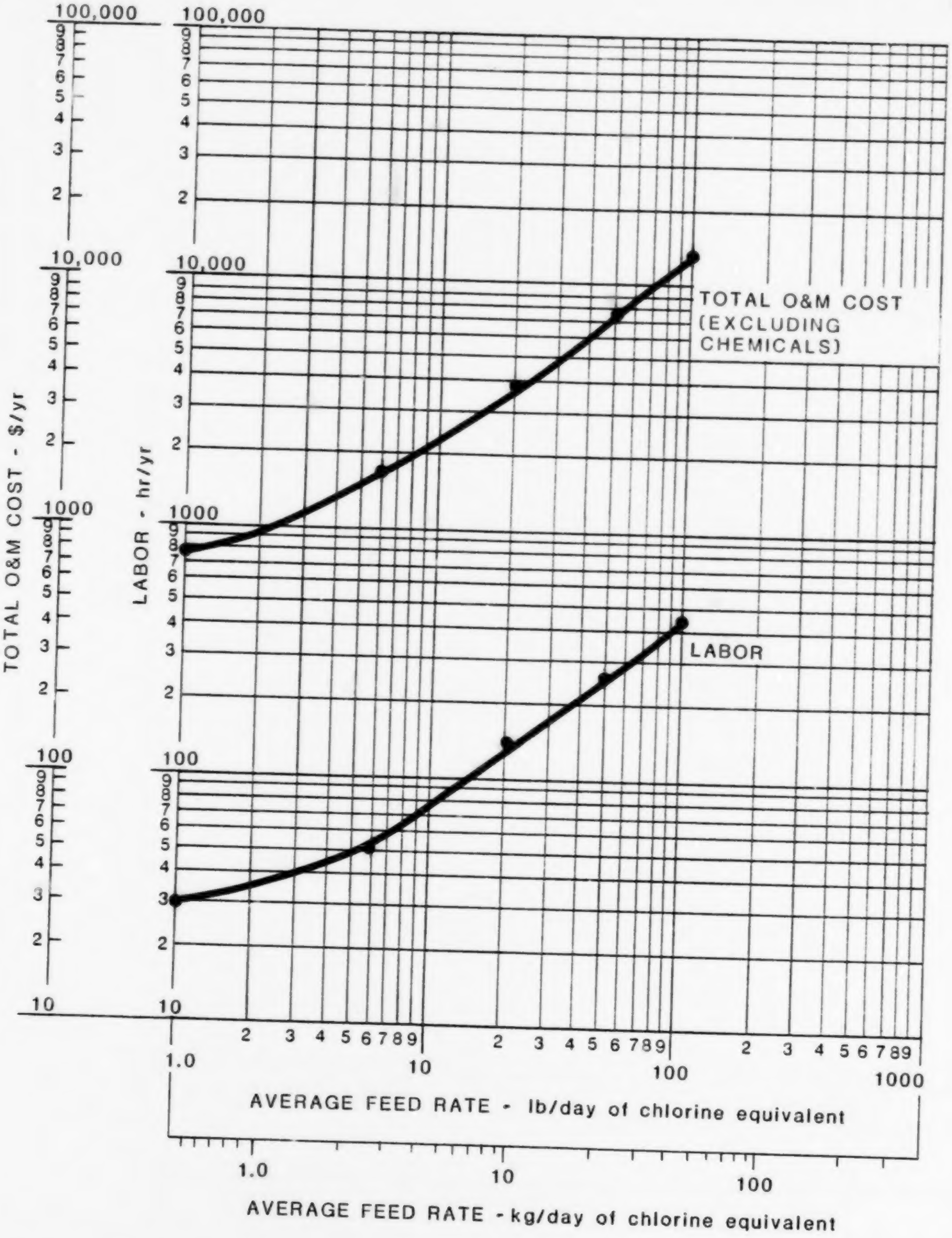


Figure 95. Operation and maintenance requirements for on-site hypochlorite generation systems - labor and total O&M cost.

CHLORINE DIOXIDE GENERATION AND FEED SYSTEMS

Introduction

Chlorine dioxide is used in water treatment for both disinfection and oxidation. It has been shown to be effective in control of taste and odors, as well as iron and manganese oxidation. Chlorine dioxide is also useful for the control of trihalomethane (THM) formation, since it does not react with THM precursors. While chlorine dioxide is not a stronger oxidant than chlorine, it has been found that doses associated with both disinfection and oxidation are significantly less than those associated with chlorine. However, the cost of using chlorine dioxide for disinfection is greater than for use of chlorine.

Chlorine dioxide gas can not be purchased in cylinders because it is unstable at concentrations above 10%, and is sensitive to compression. For this reason, chlorine dioxide used in water treatment applications is generated on-site, usually in response to demand. However, chlorine dioxide solutions can be stored for extended periods of time without loss of strength. Chlorine dioxide gas is extremely soluble in water, and has a greenish-yellow or red-yellow color, depending upon the concentration in the solution.

The most common method of generating chlorine dioxide for use in water treatment applications is by reaction of a chlorine solution with an acidified sodium chlorite ($NaClO_2$) solution, according to the following reactions:

Chlorine Solution Reaction

$$H_2O + Cl_2 \rightarrow HOCl + HCl$$

Chlorine Dioxide Generation Reaction

$$2NaClO_2 + HOCl + HCl \rightarrow 2ClO_2 + 2NaCl + H_2O$$

In the generation reaction, it can be seen that the equilibrium can be shifted to favor chlorine dioxide production by increasing the concentration of hydrogen ions (lowering the pH). A pH of 4 or less is generally considered to be optimum. One method of accomplishing this is to provide an excess of chlorine in solution. However, this has been shown to initiate a competing reaction that destroys the chlorine dioxide once it has been formed. Additionally, if more than a small amount of excess chlorine is present, problems may result due to formation of trihalomethanes in the finished water. A second, and usually preferable method of lowering pH is by the addition of hydrochloric acid.

Hydrochloric acid produces better results than the use of excess chlorine, and usually at a lower cost. Therefore, the modified chlorine dioxide generation procedure adds hydrochloric acid to the sodium chlorite solution prior to mixing with the chlorine solution. It has been shown that this increases both the purity of the chlorine dioxide solution, increases the overall yields, and eliminates problems with THM formation if the chlorine dose is carefully controlled.

Mixing of the chlorine solution and the acidified sodium chlorite solution occurs in a reactor filled with Raschig rings. Generally, the reactor is a glass or PVC cylinder, with upward flow through the cylinder. Glass is advantageous, as it allows the reaction to be observed visually, as the greenish-yellow chlorine dioxide is formed. If PVC is used, a separate sight glass is necessary.

In extremely low production systems where continuous production is not practical, the aqueous chlorine dioxide may be stored in a solution tank and metered into the process flow. The batch operation may be run once or twice a week with subsequent metering of the chlorine dioxide solution into the process stream. The generated chlorine dioxide solution must be protected from light and stored in a covered container.

In designing the chlorine dioxide generating and feed systems, special consideration should be given to storage facilties for sodium chlorite. Sodium chlorite should be handled with a minimum of spilling and any spilling should be flushed with large quantities of water. Sodium chlorite is a strong oxidant and under slightly damp conditions may be extremely hazardous, posing a fire and explosion hazard. Sodium chlorite solutions should be prepared using soft water. The costs associated with capital construction of chlorine dioxide generation and feed facilities, as well as costs for operation and maintenance must include appropriate water softening facilities. As many installations will have sufficiently soft water, no cost is included for water softening. An alternative, especially for small systems preparing the sodium chlorite solution on-site from dry sodium chlorite, is to purchase commercially available prepared sodium chlorite solutions. Use of a prepared solution increases sodium chlorite costs by 15 to 20% plus additional freight costs. Bulk dry sodium chlorite should be stored in an outside building, preferably detached from any main structure. The cost of this facility may significantly increase the cost of the chlorine dioxide generation and feed system.

Impact of Raw Water Quality on Treatment Cost

In the past, typical chlorine dioxide dosages have been between 0.1 and 2.5 mg/L, depending upon the concentration of bacteria, organics, iron and manganese, and other reducing compounds present in the water. Recently, however, the EPA recommended that the concentration of total residual oxidants (chlorine dioxide and chlorite) be kept to less than 1.0 mg/L.[1] This recommendation is based upon health effects of chlorine dioxide and chlorite to certain individuals. Some installations using high dosages may have to lower the dosage to meet this recommendation.

Chlorine dioxide demand tests may be used to determine required chlorine dioxide dosages. Chlorine dioxide is relatively expensive compared to most other oxidants, and in many cases, economics of treatment may be a factor in establishing the dosage.

Construction Costs

Construction costs which were developed are for generation using a chlorine solution mixed with an acidified sodium chlorite solution. The chlorine is produced using gaseous chlorine metered into water using a conventional chlorinator. Hydrochloric acid and sodium chlorite solutions are prepared in separate day tanks, and metered to a mixing point using a dual head metering pump. These two solutions are mixed together prior to mixing with the chlorine solution immediately ahead of the chlorine dioxide generator. All equipment is housed in a 11.2 m^2 (121 sq ft) building with a 3.05 m (10 ft) height. A typical layout is presented in Figure 96. The construction costs shown in Table 107 and Figure 97 are applicable to feed rates up to 77.2 kg/d (170 lb/day).

TABLE 107. CONSTRUCTION COST SUMMARY FOR CHLORINE DIOXIDE GENERATION AND FEED EQUIPMENT

Cost Category	Cost
Excavation and Sitework	$ 1,100
Manufactured Equipment	11,000
Concrete	400
Labor, Installation	4,100
Pipe and Valves	3,000
Electrical, Instrumentation	1,900
Housing	10,000
Subtotal	31,600
Design Contingencies	4,800
Total	$36,400

Note: These costs include $2,800 for hydrochloric acid feed facilities. Hydrochloric acid is used to decrease pH to the optimum level for chlorine dioxide formation.

Operation and Maintenance Requirements and Costs

Costs for operation and maintenance for a chlorine dioxide generation and feed system are similar to those associated with a gas feed chlorination system. Additional costs result from operation and maintenance of solution metering pumps, and preparation of the hydrochloric acid and the sodium chlorite solutions.

Process energy is required for the chlorination system booster pump, the dual head metering pump, and process control. Building energy, based upon a lighting requirement of three hours per day, is 156 kwh/m^2/y (14.5 kwh/sq ft/year) for lighting, ventilation, and heating.

Maintenance material includes components required for periodic repair of the two pumps, the chlorinator, and the electrical controls.

Labor requirements consist of daily checking of the generation system, including daily analysis of the chlorine dioxide residual, periodic changing of chlorine tanks, and preparation of hydrochloric acid and sodium chlorite solutions. Maintenance of equipment, as required, is also included in the labor requirements.

Table 108 summarizes operation and maintenance requirements which are also shown in Figures 98 and 99.

TABLE 108. OPERATION AND MAINTENANCE SUMMARY FOR CHLORINE DIOXIDE GENERATION AND FEED EQUIPMENT

Feed Rate, lb/day	Energy, kwy/yr Building	Energy, kwy/yr Process	Energy, kwy/yr Total	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.11	1,800	2,500	4,300	400	180	2,700
2.2	1,800	8,300	10,100	500	180	3,200
21.9	1,800	16,700	18,500	700	350	5,900
43.8	1,800	20,000	21,800	800	1,050	13,900

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

Although chemical cost and freight associated with chemical costs vary widely, an estimate of the chemicals required, their cost, and the total annual chemical cost to produce chlorine dioxide at different rates is shown in Table 109.

Field Data Collection

Field operating data were collected at two locations which utilize chlorine dioxide for the oxidation of iron prior to removal by filtration. These two locations were Villa Rica, Georgia, and Fayetteville, Georgia. The chlorine dioxide dosages were 2.26 kg/d (5 lb/day) and 2.7 kg/d (6 lb/day) respectively.

A comparison of field operating data with Figures 98 and 99 is shown following:

	Villa Rica Field Data	Villa Rica Data From Figures 98 and 99	Fayetteville Field Data	Fayetteville Data From Figures 98 and 99
Electrical Energy, kwh/hr				
Process	3,960	10,000	11,200	10,200
Building	-	1,800	-	1,800
Total	3,960	11,800	11,200	12,000
Maintenance Material, $/yr	300	600	0	600
Labor, hr/yr	120	180	101	180

TABLE 109. TYPICAL CHEMICAL COSTS FOR CHLORINE DIOXIDE GENERATION AND FEED EQUIPMENT

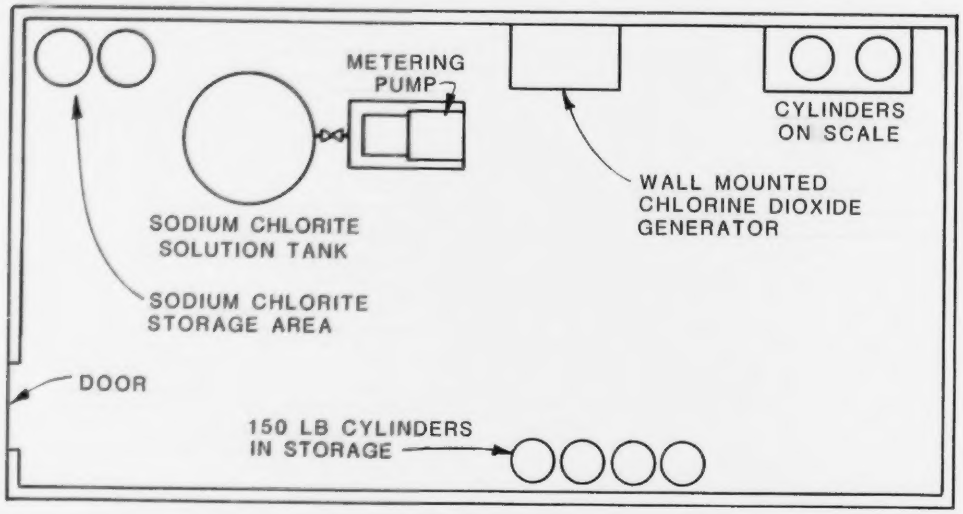
Chlorine Dioxide Feed Rate, lb/day	Chlorine			Sodium Chlorite			Hydrochloric Acid			Total Annual Chemical Cost, $/yr
	lb/day	$/lb	$/yr	lb/day	$/lb	$/yr	lb/day	$/lb	$/yr	
0.05	0.0295	1.10	12	0.084	4.50	138	0.05	0.30	6	156
0.10	0.059	1.10	24	0.168	4.50	276	0.10	0.30	11	310
1.0	0.59	1.10	240	1.68	3.75	2,300	1.0	0.30	110	2,650
5.0	2.95	0.15	160	8.40	2.50	7,670	5.0	0.30	550	8,380
50.0	29.5	0.15	1,620	49.6	2.50	45,260	50	0.30	5,500	52,380

Notes:
1. Chlorine for three smaller sizes is 10% sodium hypochlorite, which at a cost of \$0.88/gal is equivalent to \$1.10/lb free available chlorine.
2. Chlorine for larger sizes is chlorine gas purchased in cylinders. Cost is \$300/ton, or \$0.15/lb.
3. The two smallest systems use liquid sodium chlorite, and the three larger systems use dry sodium chlorite.
4. Chlorine requirements are 0.59 lb per lb of chlorine dioxide generated and sodium chlorite requirements are 1.68 lb of technical grade (80% pure) sodium chlorite per lb of chlorine dioxide generated.

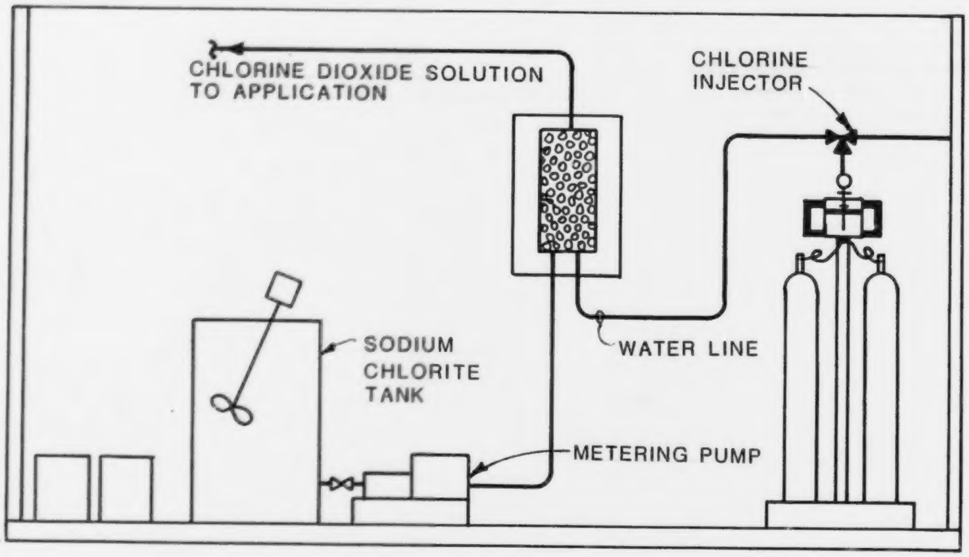
Total energy requirements at Villa Rica may be high because they were a disaggregation of total plant energy requirements into energy requirements for a number of different treatment processes, one of which was chlorine dioxide generation and feed. With the exception of Fayetteville, where there was no cost for maintenance material, other field data correlates satisfactorily with Figures 98 and 99.

References

1. "Guidance For the Sampling, Analysis and Monitoring of Trihalomethanes in Drinking Water," Science and Technology Branch, Criteria and Standards Division, U.S. EPA, Washington, D.C., February 1983.


METERING PUMP
CYLINDERS ON SCALE
WALL MOUNTED CHLORINE DIOXIDE GENERATOR
SODIUM CHLORITE SOLUTION TANK
SODIUM CHLORITE STORAGE AREA
DOOR
150 LB CYLINDERS IN STORAGE

PLAN VIEW


CHLORINE DIOXIDE SOLUTION TO APPLICATION
CHLORINE INJECTOR
SODIUM CHLORITE TANK
WATER LINE
METERING PUMP

ELEVATION VIEW

Figure 96. **Typical chlorine dioxide generation and feed installation.**

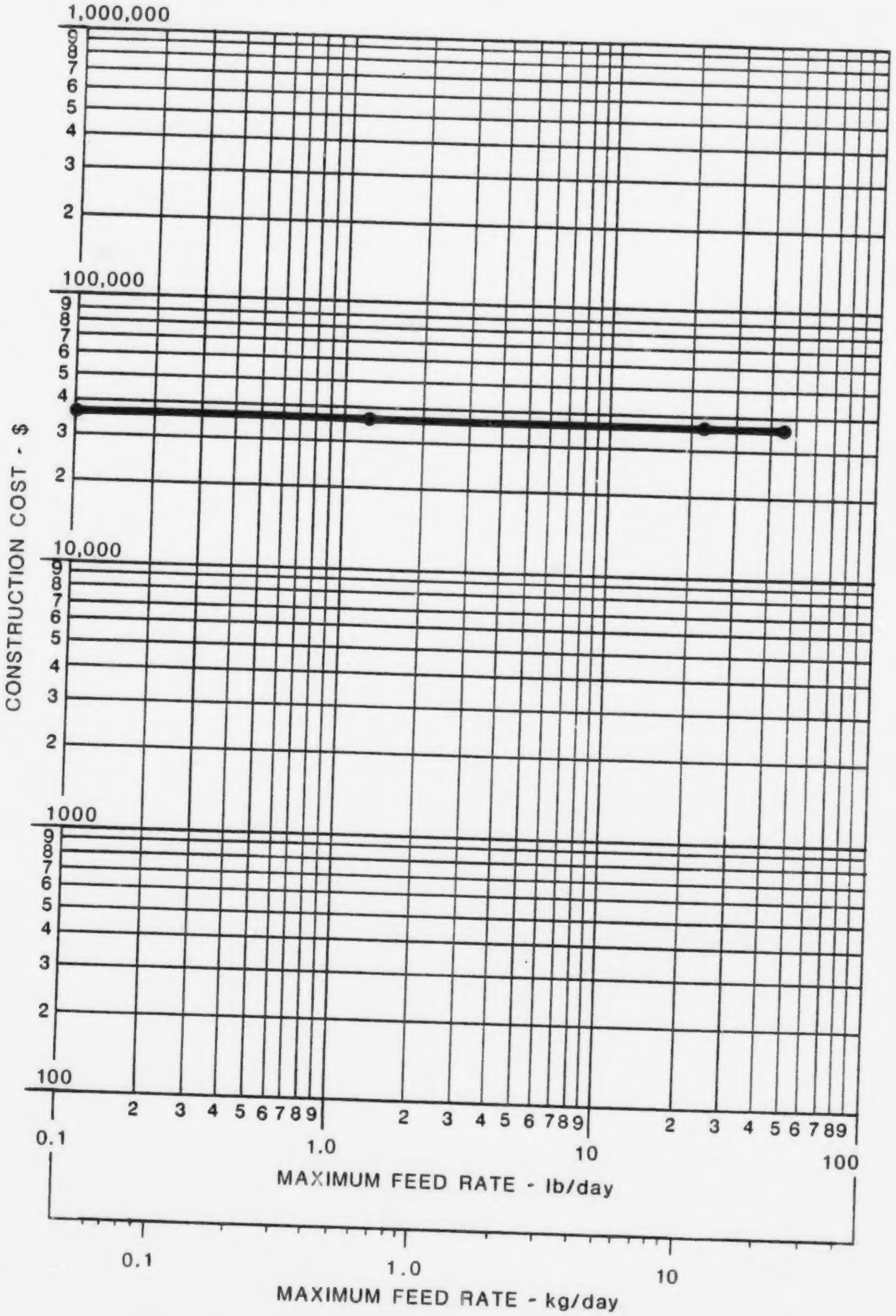


Figure 97. **Construction cost for chlorine dioxide generation and feed equipment.**

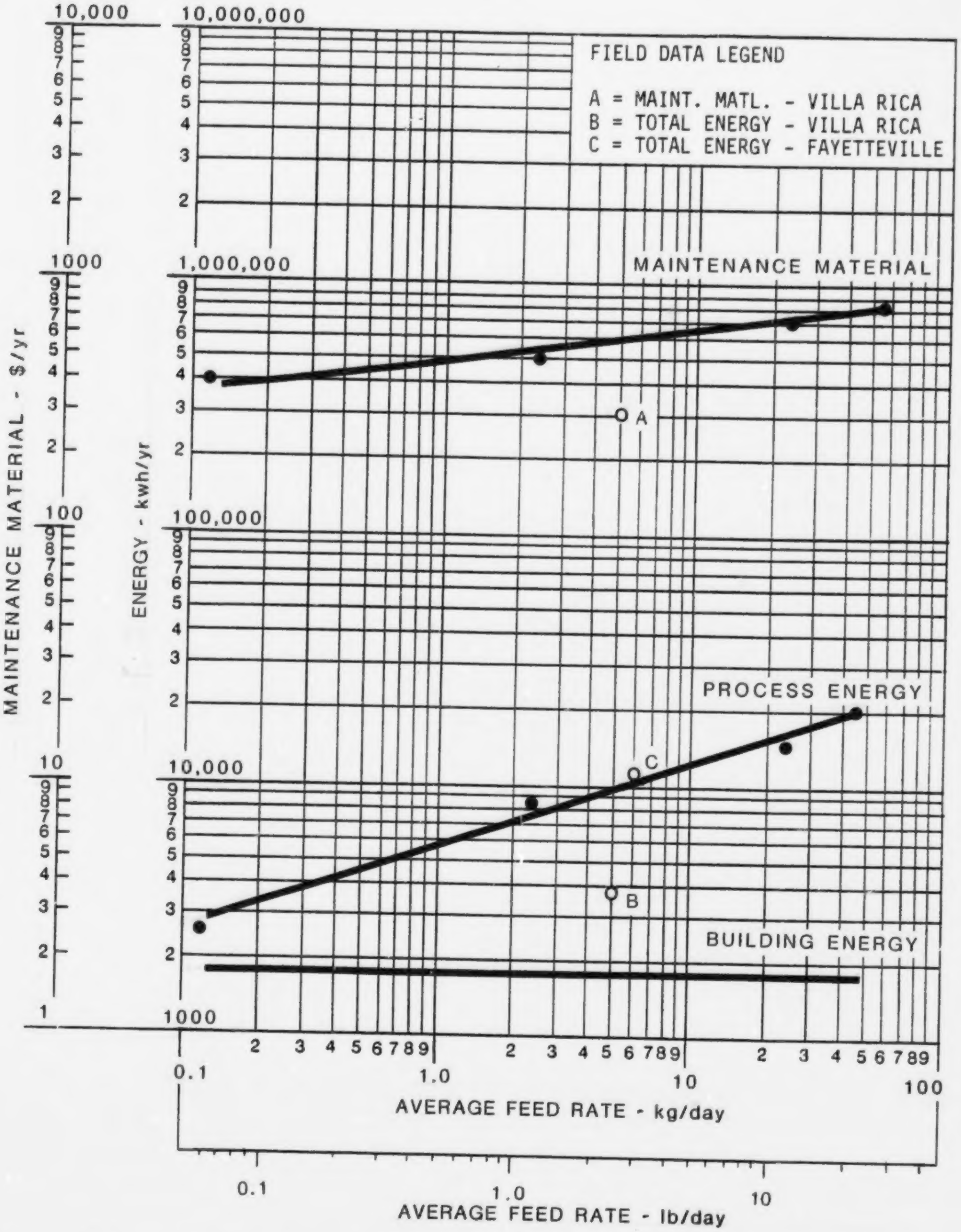


Figure 98. **Operation and maintenance requirements for chlorine dioxide generation and feed equipment - building energy, process energy, and maintenance material.**

12A

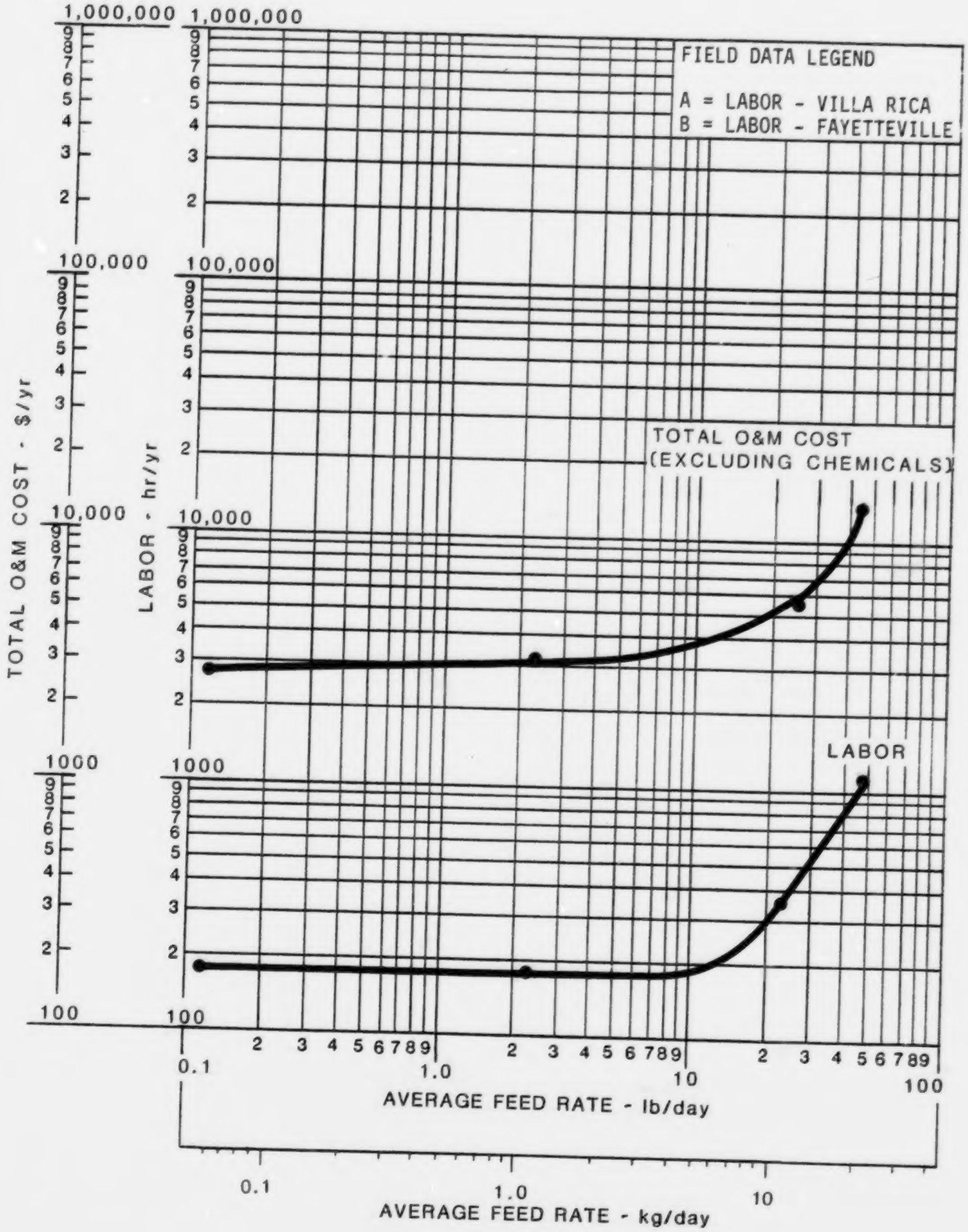


Figure 99. Operation and maintenance requirements for chlorine dioxide generation feed equipment - labor and total O&M cost.

OZONE GENERATION, FEED AND CONTACTING SYSTEMS

Introduction

Ozone is the strongest oxidizing agent available in water treatment applications. In addition to being an extremely effective disinfectant, it is also useful for oxidation of the following types of compounds: taste and odor compounds, certain organics, iron and manganese, and reducing agents such as sulfides.

To generate ozone, either air or oxygen may be used as the feed stream. If air is used, it must be filtered for particulates, cooled and dried prior to being fed to the ozonator, in contrast to oxygen from cylinders or tanks, which can be fed directly to the ozonator. Cooling and drying air requires energy, and thus ozone generation using air feed requires more energy than generation using oxygen which has been purchased. Another factor to consider is that the output of most ozonators is approximately doubled when ozone is the feed.

A typical ozone system using air as the feed source would consist of the following units: air filter, air compressor, air cooling and drying system, the ozone generation unit, the contactor, and a destruction device for the off-gases from the contactor. Different manufacturers use a variety of water cooling, refrigerant cooling, and dessicant drying systems to prepare the air to a -45.6°C (-50°F) dew point for the ozonator. If oxygen from cylinders or tanks is used as a feed, the air compressor and drying system are not required.

The contactor for a small water treatment plant would typically be a serpentine flow (up and down) in a baffled concrete chamber, or a tall fiberglass contactor operated countercurrently. Ozone may also be added ahead of an in-line mixer. When a contactor is used, either fine bubble diffusers or positive pressure injection systems are typically used. Contactors must be covered to prevent release of off-gases, and to contain unused ozone for subsequent destruction. Contactors are typically designed for a detention time of about 10 minutes, and an overall water depth of about 4.57 m (15 ft). Generally, the pressure of the ozone downstream of the generator is sufficient to move the ozone through the contactor. Although it is possible to recycle off-gases, most small installations would utilize only a once through system. Destruction of the off-gases is typically accomplished with a catalyst, thermally, or a combination of the two.

Materials used in and around the ozone system must be capable of withstanding highly oxidizing conditions, which precludes the use of rubber materials. Typically, stainless steel or teflon piping is utilized.

The hazards of ozone gas leaks in and around the generator and contactor should not be underestimated. Ozone is a toxic and dangerous gas and requires operator protection similar to gas fed chlorination systems. Generally, an air tight room is utilized for the ozonation equipment, with an ozone monitor installed. High ozone concentrations in the room should activate an alarm and room ventilation equipment, and shut down the ozone generati[illegible]quipment.

Impact of Raw Water Quality on Treatment Cost

Ozone dosages depend to a great extent on the pretreatment utilized, and the type of compound(s) being oxidized. Adequate bacterial disinfection can generally be attained with dosages of 1.5 to 2.0 mg/L if turbidity is less than 1 NTU. Viral inactivation is reported to occur when the initial ozone demand is satisfied and a 0.4 mg/L ozone residual is maintained for 4 minutes after the ozone demand has been satisfied.[1]

Oxidation requirements for inorganics and organics will be quite variable, depending upon the compound and its concentration. Laboratory studies should be conducted to determine appropriate ozone dosages.

Construction Costs

Construction costs are presented separately for ozone generation and feed systems, and for ozone contactors. This approach allows variation of ozone contactor detention time independent of ozone feed rate. For ozone generation and feed systems, costs are presented for both air feed and oxygen feed to the ozonator.

Construction costs for ozone contactors are based upon concrete contactors which use serpentine flow in an upflow/downflow configuration. Ozone dissolution equipment is located at the bottom of the downflow pass, thus providing countercurrent flow. The construction costs include the ozone dissolution equipment, and manways which can be used for access to the interior of the contactor. Conceptual designs for ozone contactors are presented in Table 110, and construction costs are presented in Table 111 and in Figure 100.

TABLE 110. CONCEPTUAL DESIGNS FOR OZONE CONTACTORS

Contactor Volume, gal	Contactor Dimensions, LxWxH, ft	Water Depth, ft
2,000	8.9x2x16.5	15
4,200	12.5x3x16.5	15
6,900	15.3x4x16.5	15
10,000	19.8x4.5x16.5	15
15,000	24.3x5.5x16.5	15

Construction costs for ozone generation and feed systems using air feed include air preparation equipment, the ozonator, destruction equipment for contactor off gases and a building to house the equipment. For oxygen feed installations, the construction costs include the ozonator, destruction equipment for contactor off gases, and the building. Ozonators and the contactors are housed in a sealed room, similar to the typical layout shown in Figure 101. An ozone detector is located within the building; in the event of an ozone leak this detector will activate the alarm and the building ventilation system, and shut down the ozonator.

TABLE 111. CONSTRUCTION COST SUMMARY FOR OZONE CONTACTORS

Cost Category	Contactor Volume, gal 2,000	4,200	6,900	10,000	15,000
Manufactured Equipment	$ 6,400	$ 6,400	$ 6,400	$ 6,400	$ 6,400
Concrete	8,300	12,900	16,800	21,500	28,000
Pipe and Valves	4,700	5,200	6,300	6,300	7,400
Subtotal	19,400	24,500	29,500	34,200	41,800
Design Contingencies	2,900	3,700	4,400	5,100	6,300
Total	$22,300	$28,200	$33,900	$39,300	$48,100

Piping is included for the ozonator cooling water, ozone, and water to and from the ozone contactor. Off-gases from the ozone contactor are destroyed using a combination thermal/catalytic destruct device.

The building ventilation system consists of an intake louver and motorized damper on one side of the building, and a fan, ductwork, and motorized damper on the opposite side of the room. This system is designed to change the room air once every two minutes, when activated. The ventilation system can be activated by the ozone detector, a switch activated by opening the building door, or a switch located on the building exterior. A shutdown switch for the ozonator is also located on the building exterior.

For required feed rates less than 2.27 kg/d (5 lb/day), there is virtually no change in equipment cost from the 2.27 kg/d (5 lb/day) unit. However, lower flow rates can be achieved using the 10:1 turndown feature of the ozonators. Thus, a 2.27 kg/d (5 lb/day) ozonator could produce between 0.23 and 2.27 kg/d (0.5 and 5 lb/day) of ozone.

Construction costs are presented in Table 112 for air feed ozonators, Table 113 for oxygen feed ozonators, and in Figure 102.

Operation and Maintenance Requirements and Costs

Process electrical energy for oxygen feed ozone generation is for the ozonator and the thermal destruction of contactor off-gas, and is approximately 7.7 kwh/kg (3.5 kwh/lb). For air feed ozone generation, process electrical energy requirements are for the ozonator air feed preparation to -45.6°C (-50°F) dew point, ozonator operation, and thermal destruction of contactor off-gas. Process electrical energy for air feed systems varies between 11 kwh/kg (5 kwh/lb) and 17.6 kwh/kg (8 kwh/lb) of ozone produced. The lower level corresponds to the solid state technology ozonator using titanium oxide ceramic electrodes produced by one manufacturer, and the higher level to the glass dielectric ozonators using high tension transformers, produced by other manufacturers. Cooling water required for cooling the compressed air and the ozonator was assumed to be available on-site and no costs are included. Cooling water requirements are generally in the range of 0.32-0.63 L/s (5-10 gpm).

TABLE 112. CONSTRUCTION COST SUMMARY FOR OZONE GENERATION AND FEED SYSTEMS, AIR FEED

Cost Category	Feed Rate, lb/day				
	5	12	20	40	110
Excavation and Sitework	$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500
Manufactured Equipment					
Ozonator	26,800	34,200	40,700	57,800	107,000
Other Equipment	13,400	13,400	13,900	15,000	16,100
Labor, Installation	20,300	23,600	26,900	35,000	58,400
Pipe and Valves	6,300	6,300	6,300	7,300	8,300
Electrical, Instrumentation	17,700	19,700	22,400	27,700	42,600
Housing	24,200	24,200	24,200	26,400	29,000
Subtotal	112,200	124,900	137,900	172,700	264,900
Design Contingencies	16,800	18,700	20,700	25,900	39,700
Total	$129,000	$143,600	$158,600	$198,600	$304,600

Note: Under manufactured equipment, the category "other equipment" includes added building ventilation not included in the basic building cost, contactor off-gas destruction equipment, and ozone leak detector. Housing requirements are 484, 484, 484, 550, and 660 sq ft for these five systems, with a 10 ft ceiling height.

TABLE 113. CONSTRUCTION COST SUMMARY FOR OZONE GENERATION AND FEED SYSTEMS, OXYGEN FEED

Cost Category	Feed Rate, lb/day				
	10	24	40	80	220
Excavation and Sitework	$ 3,500	$ 3,500	$ 3,500	$ 3,500	$ 3,500
Manufactured Equipment					
Ozonator	18,000	23,900	29,700	44,500	85,600
Other Equipment	13,400	13,400	13,900	15,000	16,100
Labor, Installation	20,300	23,600	26,900	35,000	58,400
Pipe and Valves	6,300	6,300	6,300	7,300	8,300
Electrical, Instrumentation	17,700	19,700	22,400	27,700	42,600
Housing	24,200	24,200	24,200	26,400	29,000
Subtotal	103,400	114,600	126,900	159,400	243,600
Design Contingencies	15,500	17,200	19,000	23,900	36,500
Total	$118,900	$131,800	$145,900	$183,300	$280,100

Note: Under manufactured equipment, the category "other equipment" includes added building ventilation not included in the basic building cost, contactor off-gas destruction equipment, and ozone leak detector. Housing requirements are 484, 484, 484, 550, and 660 sq ft for these five systems, with a 10 ft ceiling height.

Building energy requirements for lighting, ventilation, and heating are 156 kwh/m^2/y (14.5 kwh/sq ft/yr) based upon a lighting requirement of three hours/day.

Maintenance material for air feed systems includes repair components for the air preparation filters, compressor, and refrigerant/dessicant air dryers; for oxygen feed systems it also includes the purchase of oxygen. The oxygen requirement is 2.5 kg/kg of ozone produced (2.5 lb/lb) at a cost of $0.74/kg ($0.335/lb) of oxygen delivered to the plant. Additionally, repair components are required for the ozonator, and the ozone contactor system, including the off-gas destruction system. The principal component needing replacement is the ozonator electrode, with replacement cost increasing greatly if the feed air is improperly prepared. A small cost is also included for electrical components which will be necessary for maintenance of the electrical control and monitoring system.

Labor is required for routine operation and maintenance requirements. Operation labor is based on one hour per day, for all capacities. Daily operational requirements consist of inspecting the apparatus for proper functioning, making necessary adjustments, and monitoring the ozone residual in the product water. Maintenance labor averages slightly more than one-half hour per day. There is no significant difference in labor requirements for air feed and oxygen feed systems.

A summary of operation and maintenance requirements is presented in Table 114 for oxygen feed and air feed systems. For the latter, requirements are presented for two levels of power consumption, which are associated with the two general types of ozonators currently on the market. Operation and maintenance requirements are also shown in Figures 103 and 104.

Typical Chemical Requirements and Costs

For oxygen feed systems, oxygen must be purchased and delivered to the plant. This cost is included in the maintenance material cost. There is no chemical cost associated with air feed ozonation systems.

Field Data Collection

Operating data for a 1.81 kg/d (4 lb/day) ozone installation were collected at the Borough of Strasburg, Pennsylvania. The unit was operating at the design capacity, and used air feed.

A comparison of field operating data and information from Figures 103 and 104 is shown following:

TABLE 114. OPERATION AND MAINTENANCE SUMMARY FOR OZONE GENERATION, FEED, AND CONTACTING SYSTEMS

Ozone Feed Rate, lb/day	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
Based on Process Energy = 3.5 kwh/lb Ozone Produced (Oxygen Feed)						
10	7,100	12,800	19,900	5,800	565	13,400
24	7,100	30,700	37,800	10,900	565	19,800
40	7,100	51,100	58,200	16,400	565	26,700
80	8,000	102,200	110,200	30,300	780	46,600
220	9,600	281,100	290,700	78,100	780	107,000
Based on Process Energy = 5 kwh/lb Ozone Produced (Air Feed)						
5	7,100	9,100	16,200	2,700	565	10,100
12	7,100	21,900	29,000	3,500	565	11,800
20	7,100	36,500	43,600	4,100	565	13,400
40	8,000	73,000	81,000	5,800	780	20,100
110	9,600	200,800	210,400	10,800	780	34,100
Based on Process Energy = 8 kwh/lb Ozone Produced (Air Feed)						
5	7,100	14,600	21,700	2,700	565	10,400
12	7,100	35,000	42,100	3,500	565	12,700
20	7,100	58,400	65,500	4,100	565	14,900
40	8,000	116,800	124,800	5,800	780	23,100
110	9,600	321,200	330,800	10,800	780	42,500

Notes: 1. For oxygen feed, maintenance material includes oxygen cost at $0.335/lb. An oxygen usage of 2.5 lb/lb of ozone produced was used in the calculations.
2. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

	Field Data	Data From Figures 103 and 104
Electrical Energy, kwh/hr		
Process	-	13,000*
Building	-	7,000
Total	20,100	20,000
Maintenance Material, $/yr	3,850	2,200
Labor, hr/yr	300	525

---

*Assumes energy requirement of 8 kwh/lb of zone generated.

Field data labor requirements may be low, as they are an estimate made by the utility of the division of personnel time between water, sewers, and streets.

Reference

1. Rice, R.G., et. al., "Uses of Ozone in Drinking Water," Journal AWWA, January 1981, p. 44.

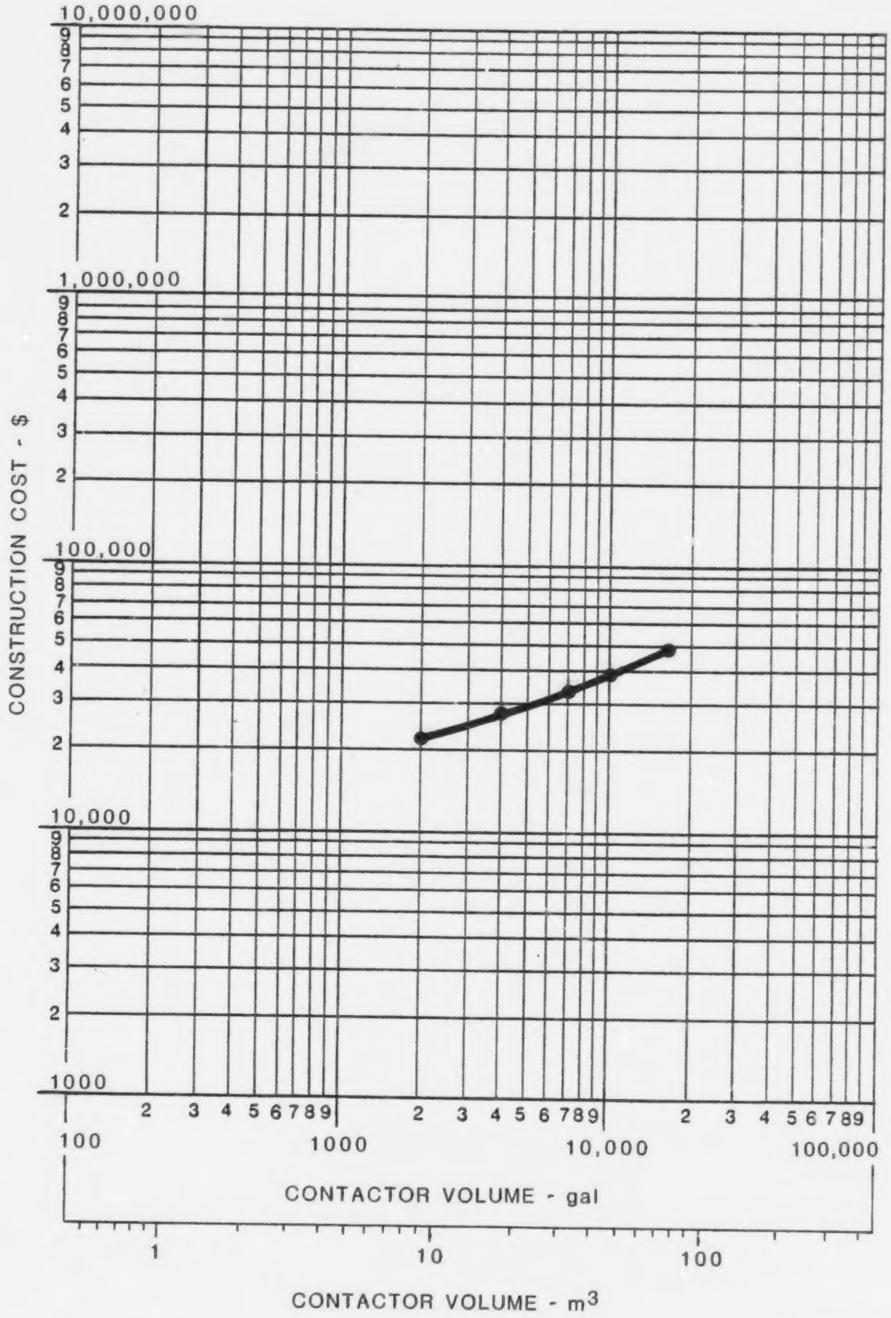
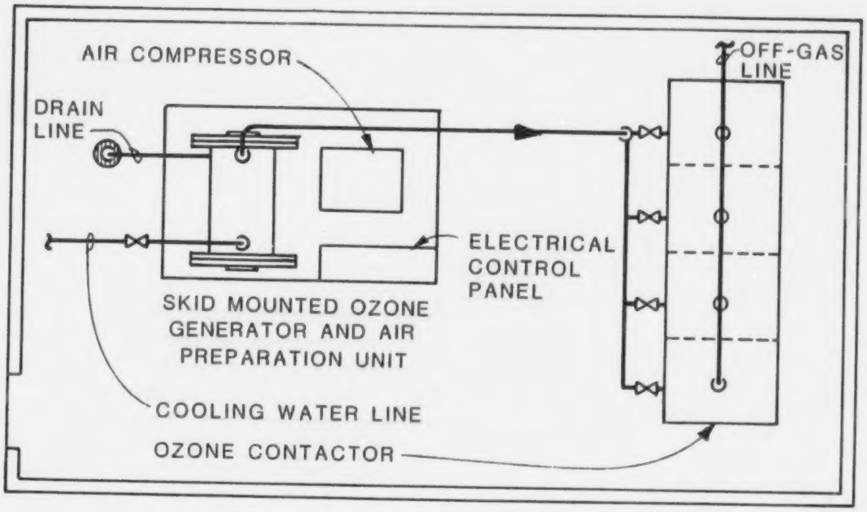
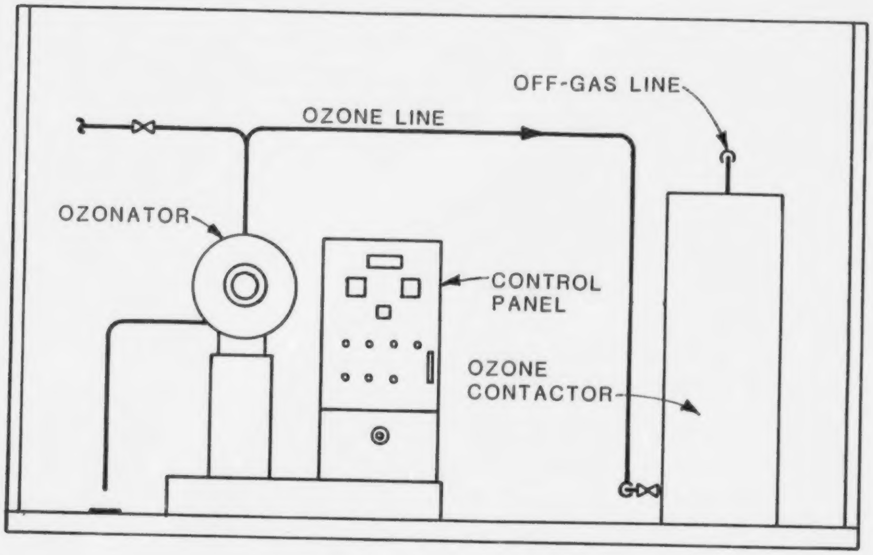


Figure 100. Construction cost for ozone contactors.


AIR COMPRESSOR
OFF-GAS LINE
DRAIN LINE
ELECTRICAL CONTROL PANEL
SKID MOUNTED OZONE GENERATOR AND AIR PREPARATION UNIT
COOLING WATER LINE
OZONE CONTACTOR

PLAN VIEW


OFF-GAS LINE
OZONE LINE
OZONATOR
CONTROL PANEL
OZONE CONTACTOR

ELEVATION VIEW

Figure 101. Typical ozone generation and contacting installation.

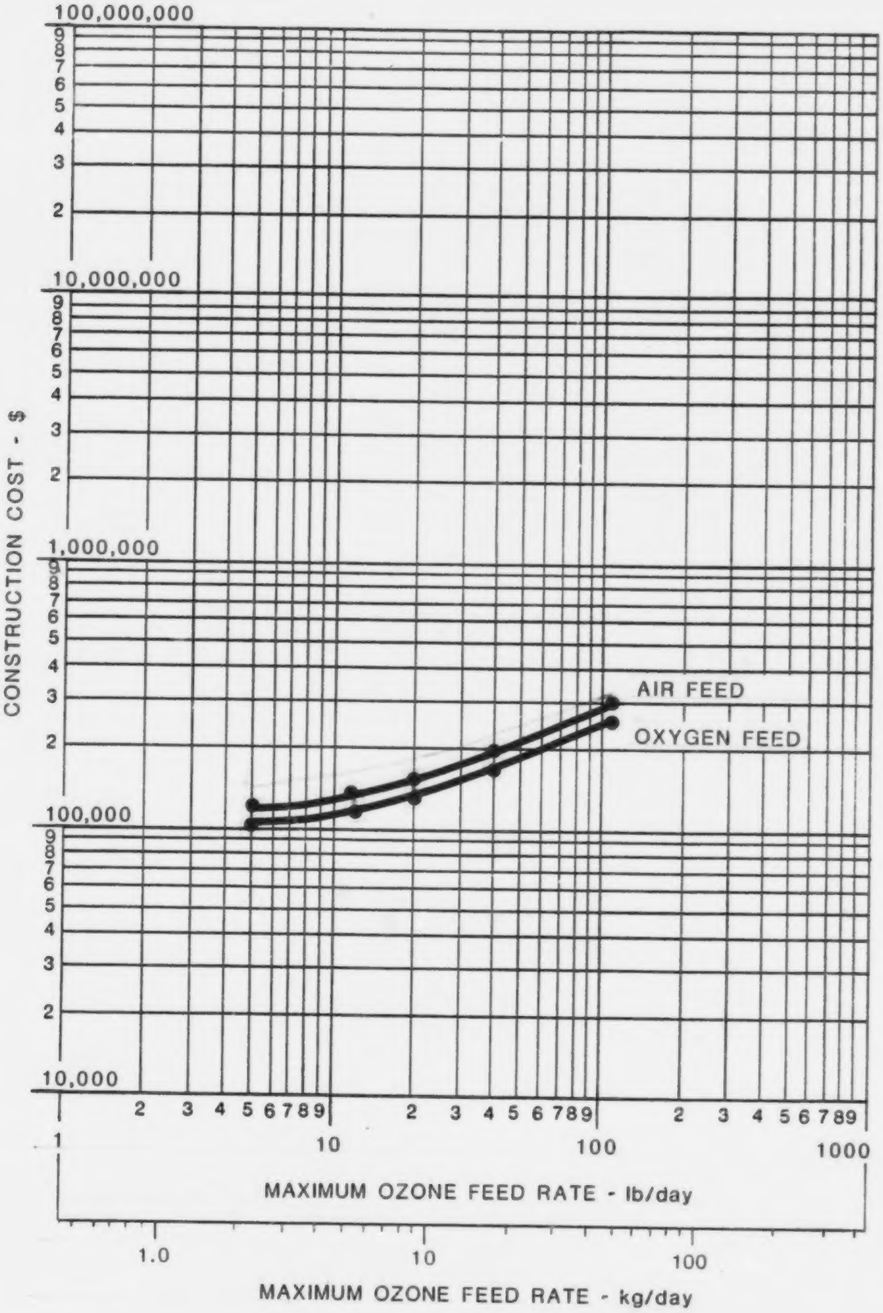


Figure 102. **Construction cost for ozone generation and feed systems.**

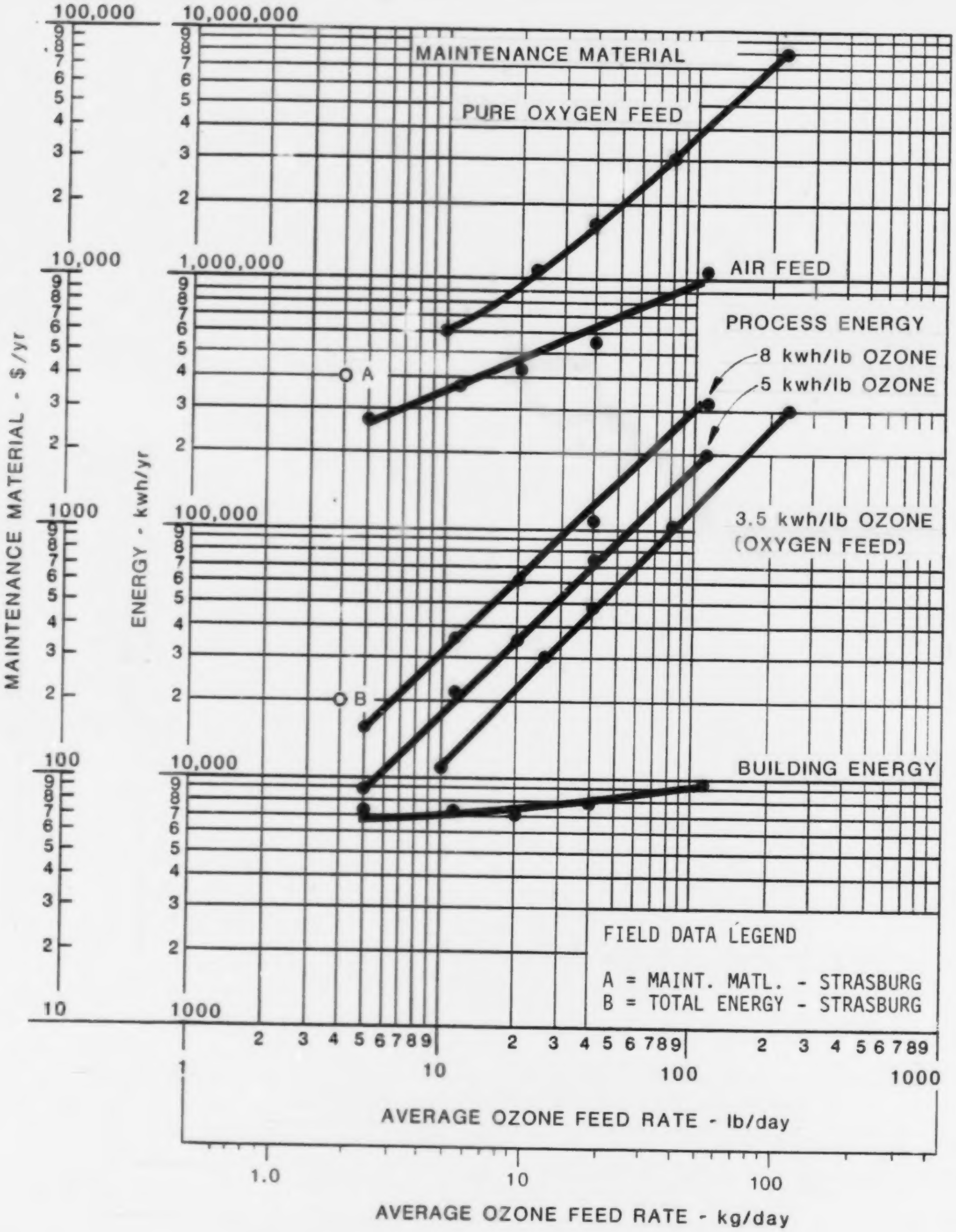


Figure 103. Operation and maintenance requirements for ozone generation, feed, and contacting system - building energy, process energy, and maintenance material.

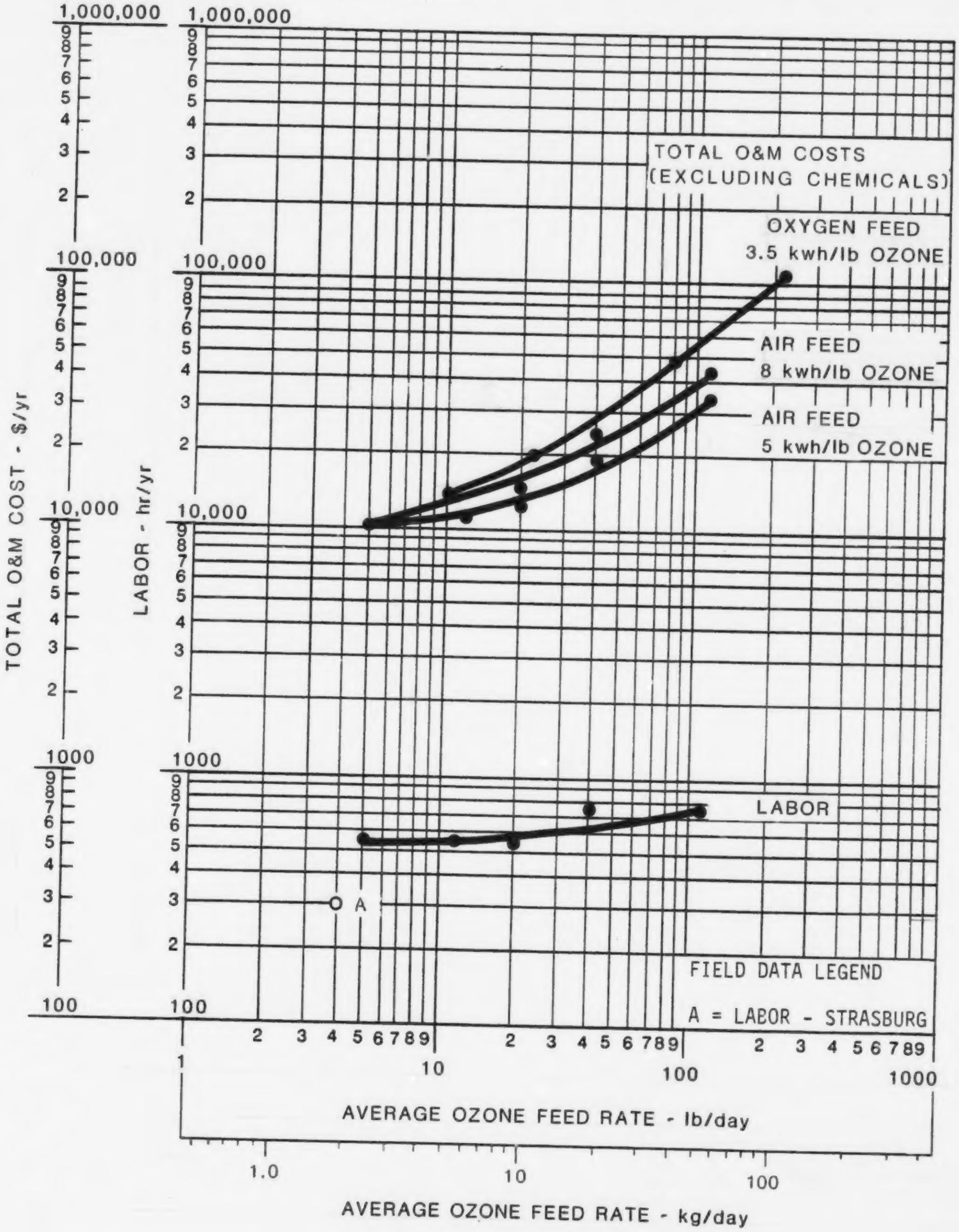


Figure 104. **Operation and maintenance requirements for ozone generation, feed, and contacting system-labor and total O&M cost.**

CHEMICAL FEED SYSTEMS

Feed systems for chemicals such as hydrated lime, soda ash, liquid or dry alum, ferrous sulfate, and sodium hexametaphosphate are very similar. Feed systems applicable to these chemicals are hereafter referred to as "Basic Chemical Feed Systems," and consist of a dissolving tank, mixer, and metering pump. Each of these chemicals can be fed at a solution concentration of about 6 percent.

A type of chemical feed system which is less common than the "Basic Chemical Feed System," but is occasionally used in small plants, is a dry chemical feeder with a mixing tank and gravity flow of the chemical slurry to the point of application; this system is hereafter referred to as a "Dry Chemical Feeder System." The chemical feed rate is controlled by the dry feeder itself and not by a metering pump. The actual flow of water through the mixing tank and to the process is not a factor in determining the chemical feed rate. This method of feeding is especially applicable to lime due to the problems of pumping lime slurries, and it is also used for alum and other dry chemicals. An advantage of this type of system is that it simplifies the procedure of adding dry chemical by eliminating the step of manually measuring the quantity of chemical to be added.

Polymers can be fed using a system similar to the "Basic Chemical Feed System" or by automatic systems. The latter automatically feeds dry polymer, mixes it, transfers it to a solution feed tank, and then meters the solution to the point of application. Once properly set, an automatic system minimizes operator time and ensures use of an accurately measured, fresh polymer solution. The systems are discussed in a following section titled "Polymer Feed Systems."

Feed systems for sulfuric acid, sodium hydroxide, potassium permanganate, and ferric chloride are specific to each of these chemicals. Costs for systems capable of feeding these chemicals are presented in following sections.

BASIC CHEMICAL FEED SYSTEMS

Introduction

The most common type of chemical feed system utilized in small water treatment plants consists of a mixing tank, mixer, and metering pump, hereafter called the Basic Chemical Feed System. Chemical solutions of known concentration are prepared on a batch basis by manually adding chemical and water to the dissolving tank. This system can be used to feed either liquid or dry chemicals. For dry chemicals, the mixing tank is used for dissolving and mixing the chemicals with water and for storage of the chemical solution. For liquid chemicals, the mixing tank is used for initial mixing and solution storage. A metering pump is used to accurately feed at a set rate, a solution of known concentration.

The Basic Chemical Feed System is applicable to the use of hydrated lime, liquid or dry alum, ferrous sulfate, ferric sulfate, and soda ash.

Construction Costs

A conceptual design including mixing tank volumes, mixer horsepowers, and metering pump capacities is presented in Table 115 for a range of chemical feed rates, and a typical system layout is shown in Figure 105. Two basic assumptions made in sizing the storage tank were that it should only be necessary to add chemicals once per day (assuming up to 24 hours per day of operation) and that the chemical should be added to produce a 6 percent solution concentration. The mixing tanks range in size from 114 to 3,785 L (30 to 1,000 gal). Mixer horsepower requirements were based on manufacturer's recommendations for the various tank sizes. Metering pump capacities were based on the daily volume of 6% solution which correlated with the storage tank size and upon standard sizes provided by manufacturers of package water treatment plants.

TABLE 115. CONCEPTUAL DESIGN FOR BASIC CHEMICAL FEED SYSTEM

	Maximum Chemical Feed Rate, lb/day						
	0.10 to 10	25	50	100	250	500	1,000
Dissolving Tank							
gal	30	50	100	200	500	1,000	2@1,000
Mixer							
hp	1/4	1/3	1/3	1/2	3/4	1.0	1.0
Pump Capacity							
gal/day	24	60	120				
gal/hr				11	22	42	84
motor horsepower	1/20	1/8	1/8	1/4	1/4	1/4	1/3

Construction costs for the Basic Chemical Feed Systems are summarized in Table 116 and are presented in Figure 106. The cost for dissolving tanks is based on using polyethylene tanks on a steel frame stand, and a mixer attached to a mixer mount connected to the stand. The pumps are diaphragm type, single head metering pumps. Pipe and valve costs allow for 6.1 m (20 ft) lengths of

TABLE 116. CONSTRUCTION COST SUMMARY FOR BASIC CHEMICAL FEED SYSTEMS

	Maximum Chemical Feed Rate, lb/day						
Cost Category	0.10 to 10	25	50	100	250	500	1,000
Dissolving Tank	$ 290	$ 430	$ 640	$ 910	$1,830	$2,200	$4,400
Mixer	180	200	200	240	410	620	620
Metering Pump	430	700	750	1,230	1,600	1,670	1,820
Pipe and Valves	180	180	220	220	280	280	420
Labor	180	180	240	260	300	330	400
Electrical	80	100	150	200	250	300	400
Subtotal	1,340	1,790	2,200	3,060	4,670	5,400	8,060
Design Contingencies	200	270	330	460	700	810	1,210
Total	$1,540	$2,060	$2,530	$3,520	$5,370	$6,210	$9,270

2.5 cm (1 in) PVC water supply, 3.8 cm (1 1/2 in) polypropylene drain pipe, and 1.3 cm (1/2 in) PVC chemical solution pipe. It was assumed that both a plant water supply line and a plant sewer line would be located nearby, and that the chemical feed line would apply chemicals to an adjacent rapid mix basin.

Operation and Maintenance Requirements and Costs

Operation labor requirements for the Basic Chemical Feed System include labor for carefully emptying bags of dry chemicals, or containers of liquid chemicals, into the dissolving tank, for turning on and off the mixer, for calibrating the chemical metering pump, and for occasional preventive maintenance of the mixer and metering pump.

Electrical requirements are for the mixer and the metering pump. Mixer operation ranges from 30 minutes per day for the smallest system up to 55 minutes per day for the largest system. It is assumed that the chemical metering pump operates continuously, 24 hours per day. The pumping head which the metering pump electrical energy requirement is based upon is 5.27 kg/cm^2 (75 psi). Pumping against a lower head will result in only a minor reduction in electricity required due to the relative inefficiencies of the pump and motor at these low pumping rates. Mixer operation for a hydrated lime feed system is required to be continuous to keep the lime solids in suspension.

Maintenance material costs are primarily for the mixer and metering pump. Maintenance material costs for a hydrated lime feed system are increased due the continuous operation of the mixer. Operation and maintenance requirements are summarized in Table 117 with a separate section presented for hydrated lime, and are presented in Figures 107 and 108.

TABLE 117. OPERATION AND MAINTENANCE SUMMARY FOR BASIC CHEMICAL FEED SYSTEMS

Average Chemical Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
For all chemicals except hydrated lime:				
0.1 to 10	120	30	200	2,200
25	250	40	270	3,000
50	250	50	290	3,300
100	480	70	300	3,400
250	560	100	410	4,700
500	660	120	490	5,600
1,000	1,040	140	820	9,200
For hydrated lime:				
0.1 to 10	1,710	35	200	2,400
25	2,360	45	270	3,200
50	2,360	55	290	3,400
100	3,670	80	300	3,600
250	5,310	110	410	5,000
500	6,940	140	490	6,000
1,000	7,080	160	820	9,700

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

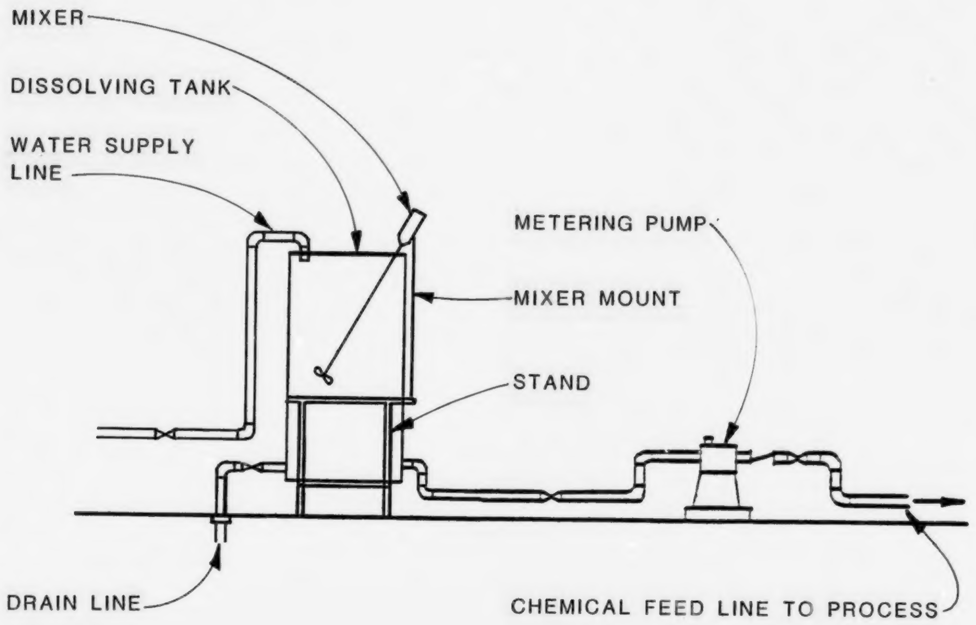

MIXER
DISSOLVING TANK
WATER SUPPLY LINE
METERING PUMP
MIXER MOUNT
STAND
DRAIN LINE
CHEMICAL FEED LINE TO PROCESS

Figure 105. Typical basic chemical feed system installation.

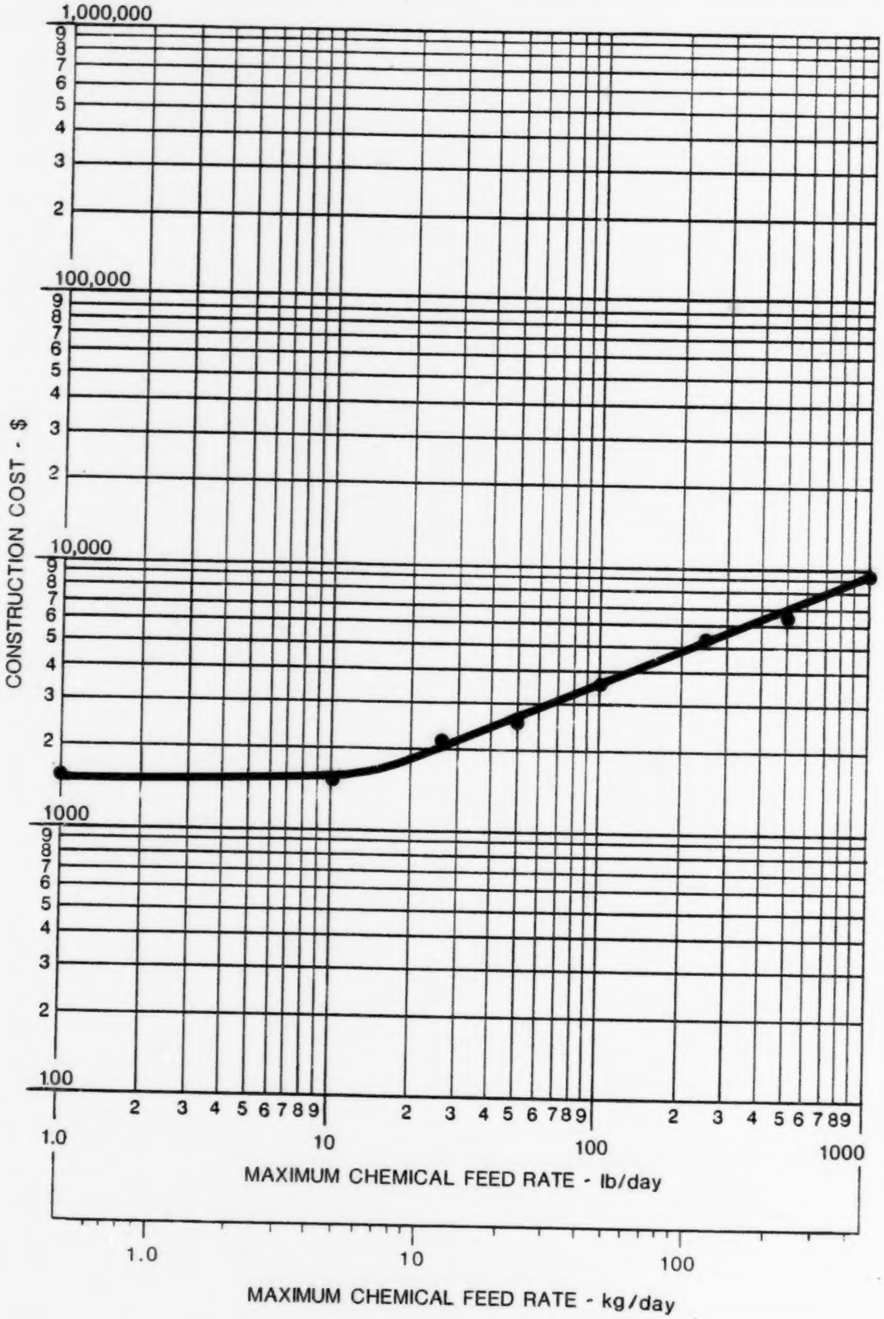


Figure 106. Construction cost for basic chemical feed systems.

20

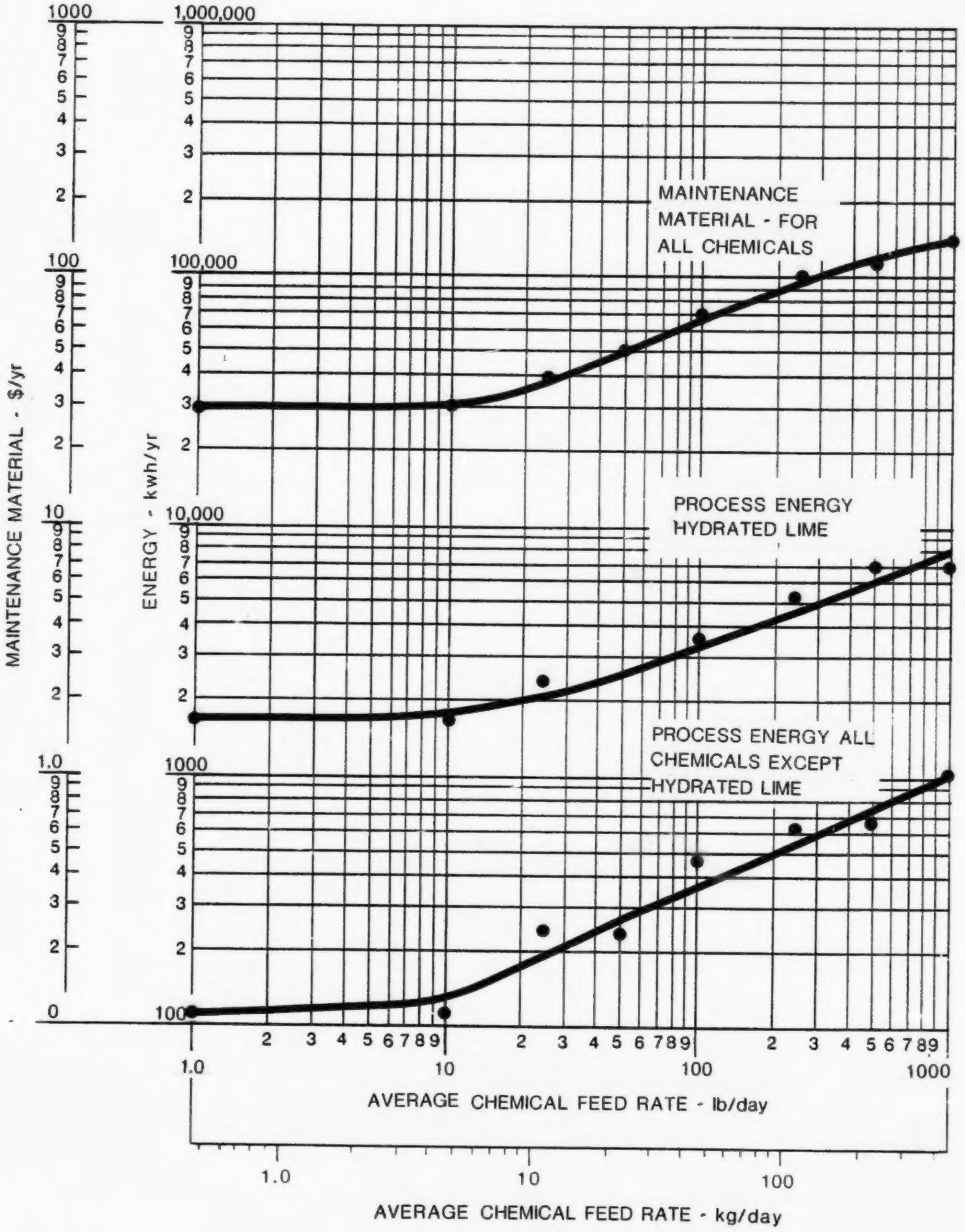


Figure 107. **Operation and maintenance requirements for basic chemical feed systems - process energy and maintenance material.**

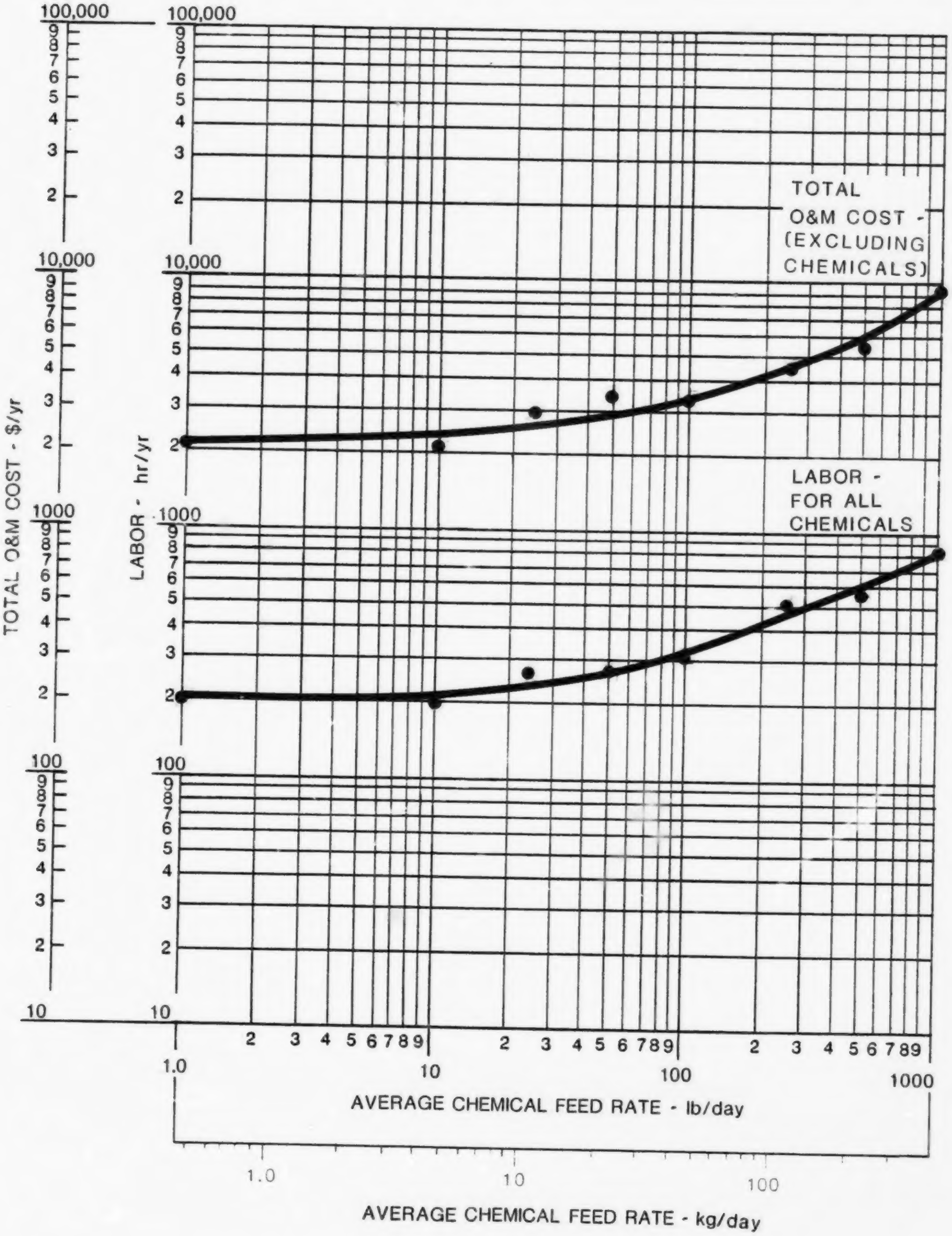


Figure 108. **Operation and maintenance requirements for basic chemical feed systems - labor and total O&M cost.**

DRY CHEMICAL FEED SYSTEMS

Introduction

Chemicals such as hydrated lime, dry alum and others listed on the following page can be fed using a dry chemical feeder with a mixing tank and gravity flow of the chemical slurry to the point of application. The chemical feed rate is controlled by the dry feeder itself and not by a metering pump. The flow of water through the mixing tank and to the point of application is continuous; the actual flow rate of water is insignificant except that sufficient water must be present to transport the chemical slurry or solution.

It is especially beneficial for lime to be fed with a dry feeder and transferred in slurry form in an open gravity trough or channel. This method allows lime scaling to be cleaned or removed much more easily than from a closed metering pump and pipeline system.

The costs presented for this dry feeder system are based upon the use of a storage hopper that holds a minimum of a one day supply of dry chemical for the largest system. This type of system would be supplied with chemical using 23 kg (50 lb) bags of chemical which are added manually to the storage hopper. The dry feeder capacity is measured in volume per unit time. The capacity range is from 0.048 to 0.93 m^3/d (1.7 to 33 cu ft/day). For hydrated lime with a density of about 480 kg/m^3 (30 lb/cu ft), the maximum system capacity would be 454 kg/d (1,000 lb/day), where twenty 23 kg (50 lb) bags per day would be required. For a system this large, the daily transfer, opening, and unloading of chemical bags generally becomes a significant burden for the plant operator(s).

A lime feed system with capacities up to 454 kg/d (1,000 lb/day) generally uses bagged hydrated lime. Only when lime consumption exceeds this rate, which is equivalent to 13.6 metric tons/month (15 tons/month), does the use of truck load bulk shipments of 13.6 to 22.7 metric tons (15 to 25 tons) start to become economical. Bulk shipments require bulk silo storage and unloading facilities which are expensive to construct and require substantial head-room for a silo.

The approximate densities of commonly used dry chemicals are as follows:[1]

	lb/cu ft	kg/m^3
Hydrated lime (high calcium)	25-35	400-560
Hydrated lime (dolomitic)	30-40	480-640
Alum (powdered)	38-45	610-720
Alum (granular)	60-63	960-1,010
Alum (lump)	62-67	990-1,070
Sodium aluminate	50-60	800-960
Ferrous sulfate	63-68	1,010-1,090
Ferric sulfate	80	1,280
Ammonium sulfate	42-47	670-750
Calcium hypochlorite (70%)	52.5	840
Sodium fluosilicate	72-85	1,150-1,360

	lb/cu ft	kg/m³
Sodium fluoride (dense)	75-86	1,200-1,380
Sodium fluoride (powdered)	50	800
Sodium hexametaphosphate	47	750
Soda ash (light)	35-40	560-640
Soda ash (extra light)	23-25	370-400
Activated carbon	28-48	450-770
Copper sulfate (crystal)	75-90	1,200-1,440
Copper sulfate (powder)	60-65	960-1,040
Potassium permanganate (crystal)	90-100	1,440-1,600

Construction Costs

Construction costs for the dry chemical feed systems are summarized in Table 118 and are presented in Figure 109. The dry feed equipment includes a screw type volumetric feeder with a capacity ranging from 0.00011 to 0.11 m^3/hr (.004 to 4.0 cu ft/hr), hopper agitation, hopper cover, and hopper low level switch. Hopper extensions which increase the hopper capacity from 0.045 m^3 up to 0.93 m^3 (1.6 cu ft to 33 cu ft) are included for the larger capacity systems. The hopper size is based on filling the hopper with dry chemical only once per day. The cost for hopper extension also includes the cost of a wooden stairway and small platform which is 1.07 m (3.5 ft) high so that bags can be lifted and emptied into a hopper which is 2.1 m (7 ft) high. The solution tank system consists of a 132 L (35 gal) fiberglass mixing tank, and a 0.19 kw (0.25 hp) mixer. Pipe and valves include a water line, a drain line, and a stub chemical feed line which will transfer the chemical solution from the solution tank to a gravity channel or trough. Construction costs for the gravity channel are not included in this cost estimate.

TABLE 118. CONSTRUCTION COST SUMMARY FOR DRY CHEMICAL FEED SYSTEMS

Cost Category	Maximum Chemical Feed Rate, cu ft/day			
	1.7	11.7	27	33
Dry Feed Equipment	$3,035	$3,035	$3,035	$3,035
Hopper Extension	0	1,080	1,480	1,680
Solution Tank	235	235	235	235
Mixer	200	200	200	200
Pipe and Valves	180	180	180	180
Labor, Installation	220	360	360	441
Electrical Equipment	270	270	270	270
Subtotal	4,140	5,360	5,760	6,040
Design Contingencies	620	800	860	910
Total	$4,760	$6,160	$6,620	$6,950

Operation and Maintenance Requirements and Costs

Labor requirements are primarily for opening bags of chemicals, carrying them, and emptying the chemical into the hopper; these labor requirements assume 10 minutes for the first 23 kg (50 lb) bag, then 5 minutes for each bag thereafter. Additional labor for preventive maintenance on the feeder and mixer amounts to between 2 and 2.5 hours per month.

Electrical energy requirements are based on continuously operating 0.19 kw (0.25 hp) motors for both the dry feeder and the mixer. Maintenance material requirements are primarily for the feeder and mixer.

Operation and maintenance requirements are summarized in Table 119 and are presented in Figures 110 and 111. These operation and maintenance requirements are based on lb/day of chemical rather than cu ft/day because the labor requirement is directly related to the weight of chemical fed which determines the number of 23 Kg (50 lb) bags to be handled per day. Construction cost estimates (presented in Table 118) are based on cu ft/day of chemical because the feeder rate and hopper size are directly related to volume of chemical fed rather than weight.

TABLE 119. OPERATION AND MAINTENANCE SUMMARY FOR DRY CHEMICAL FEED SYSTEMS

Average Chemical Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
10	3,260	80	50	900
50	3,260	80	85	1,200
100	3,260	100	115	1,600
250	3,260	100	210	2,600
500	3,260	120	365	4,400
1,000	3,260	120	670	7,700

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

References

1. "Lime Handling, Application, and Storage," Bulletin 213, National Lime Association, Washington, D.C., May 1971.

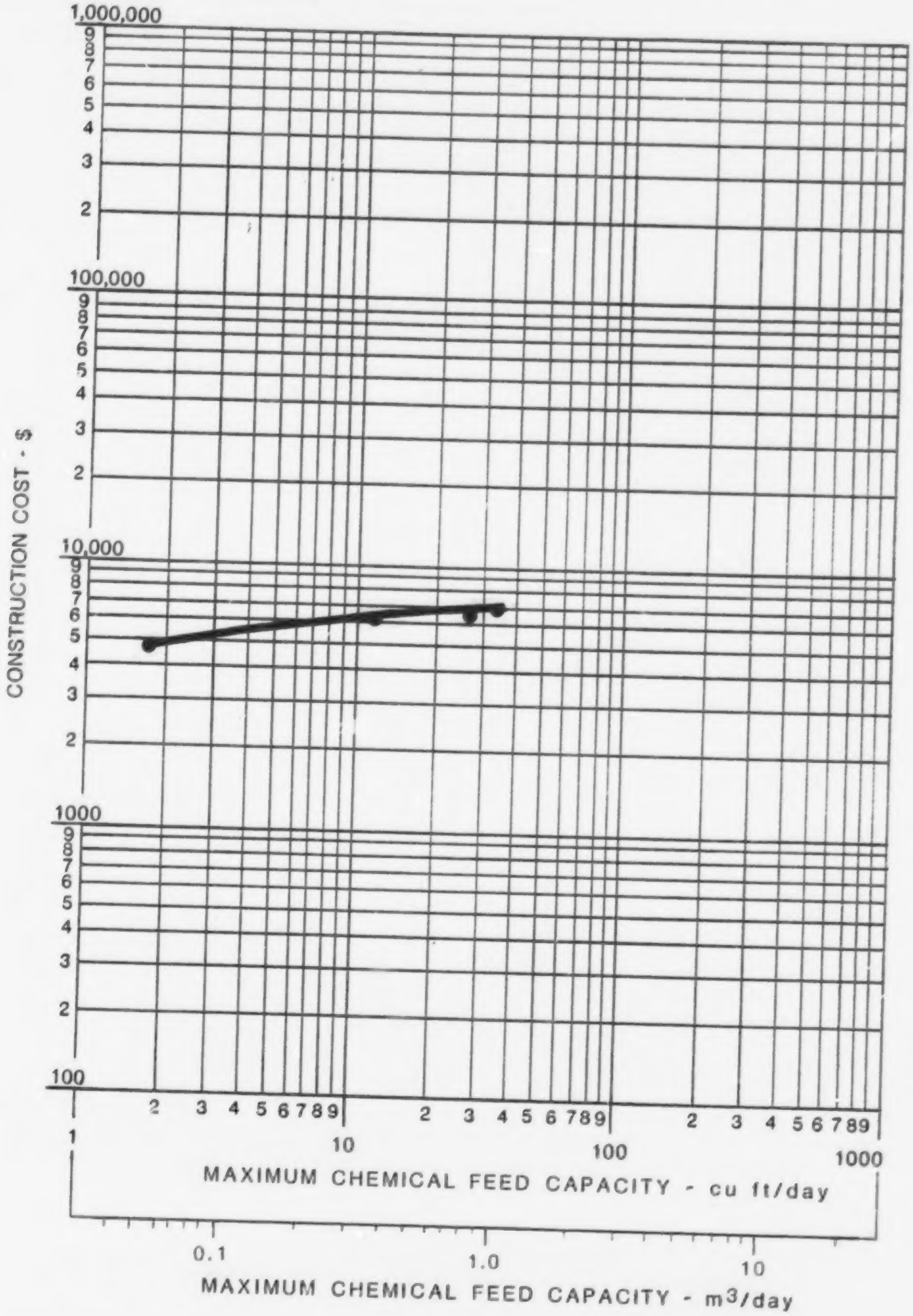


Figure 109. Construction cost for dry chemical feed systems.

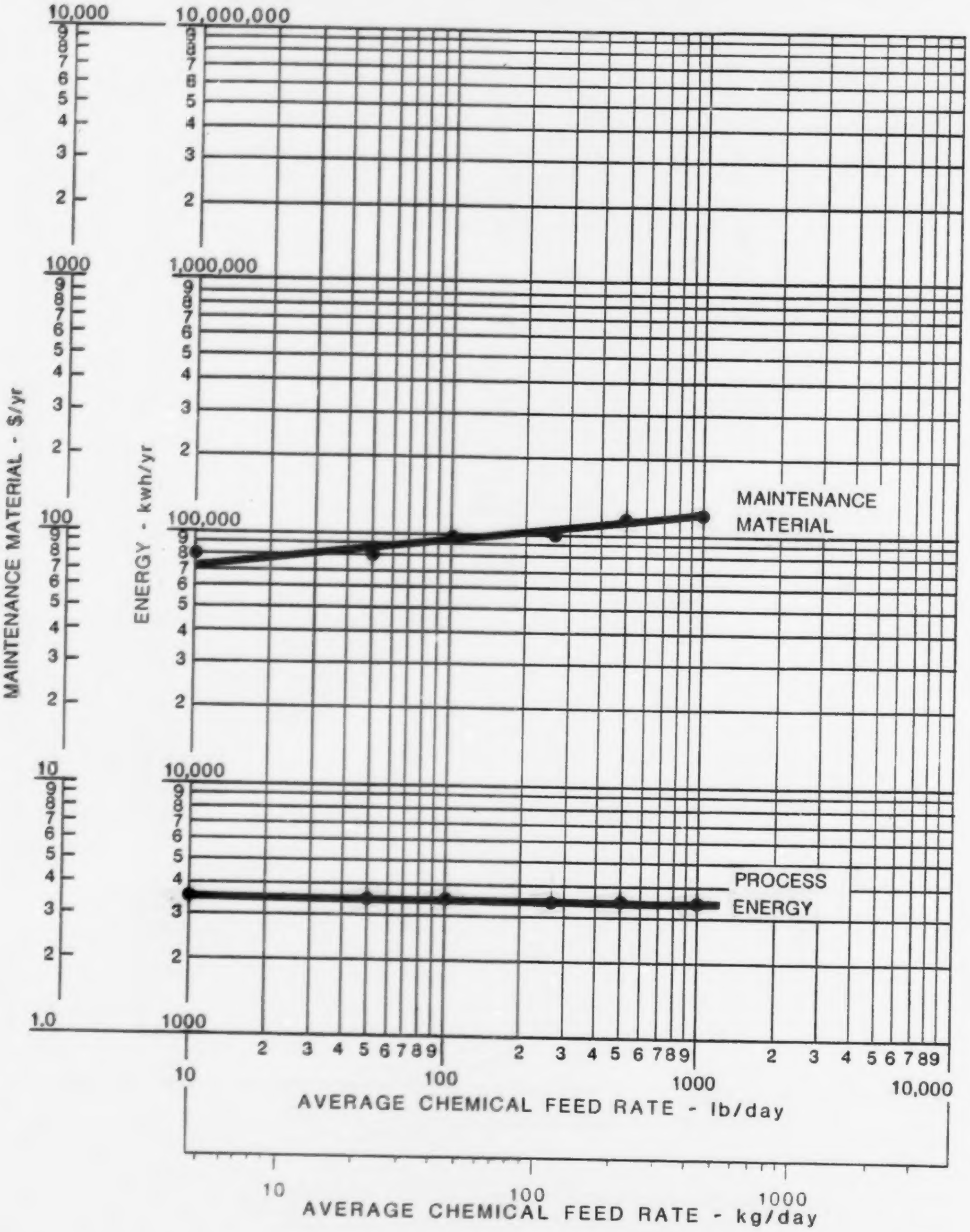


Figure 110. **Operation and maintenance requirements for dry chemical feed systems - process energy and maintenance material.**

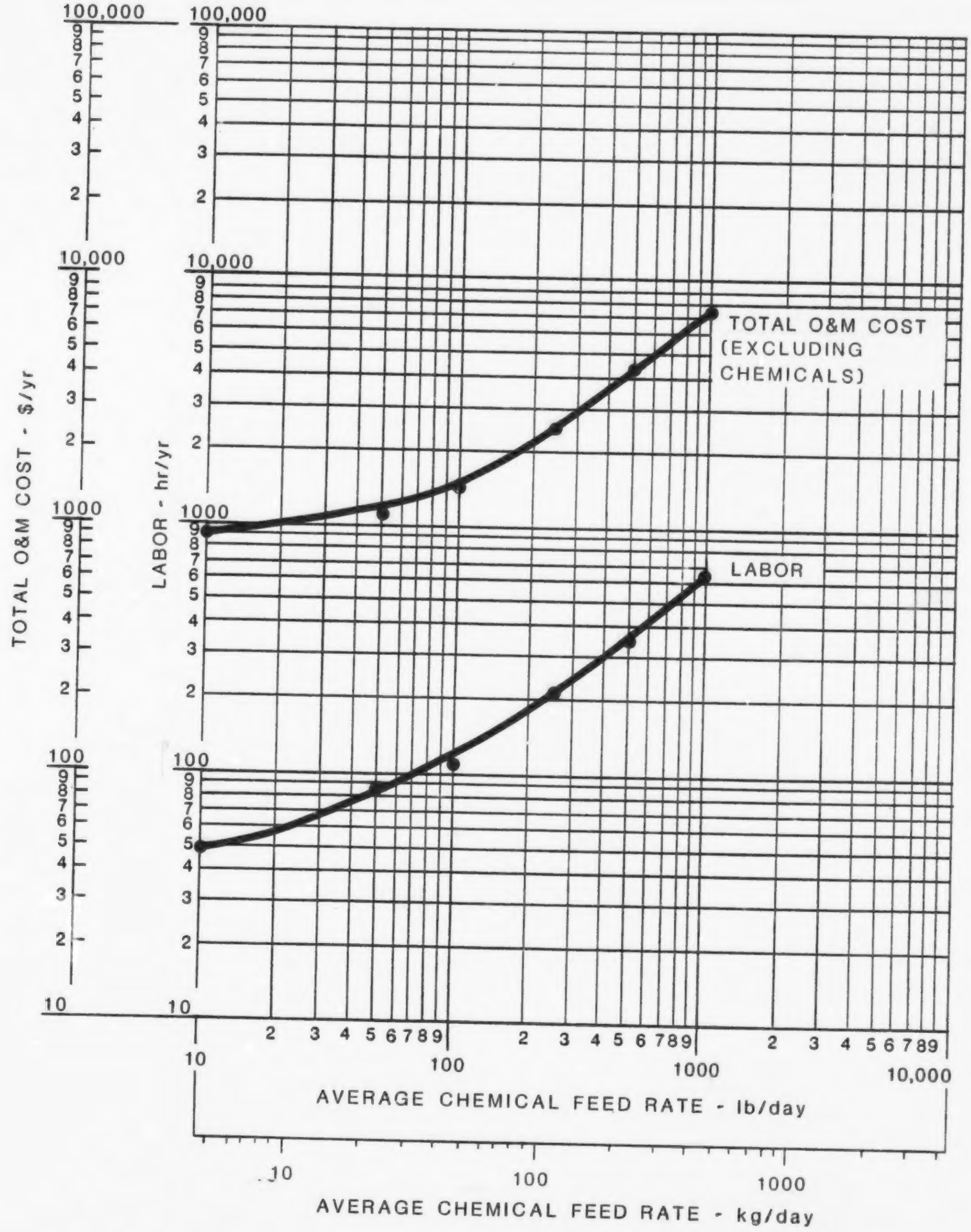


Figure 111. Operation and maintenance requirements for dry chemical feed systems - labor and total O&M cost.

POLYMER FEED SYSTEMS

Introduction

Polymer feed systems have somewhat different requirements than can be satisfied by the Basic Chemical Feed System. The major difference is that polymer solutions are much more dilute than chemical solutions such as lime slurries or alum solutions. Polymer solutions generally range in strength from 0.1 to 1.0 percent; a solution strength of 0.25 percent is assumed in this analysis. This low concentration results in larger mix tank volumes and pump capacities per pound of chemical fed. In addition, slow speed mixers required for polymers generally are more expensive than normal flash mixers.

Polymer feed systems may use either one or two mixing/storage tanks. If two tanks are used, they may be operated as parallel systems, or in series with one tank operated as a mix tank and the other operated as a storage or feed tank. The advantages of using two tanks are increased flexibility and the ability to operate continuously. The decision to use either one or two mixing/storage tanks is one of designer preference, although the two tank concept is nearly always used in plants with capacities over 567.8 m^3/d (150,000 gal/day).

Adequate polymer mixing is especially important and may require one-half to one hour per batch. In the two tank concept, if a polymer solution has been stored for longer than two or three days or if a bad batch is prepared due to improper wetting or mixing or through use of an old or previously wetted polymer, it can be disposed of while still using the last portion in the first polymer tank.

There are two schools of thought regarding the complexity of chemical and especially polymer feed systems. One concept is that the system should be as simple and inexpensive as possible, like the Basic Chemical Feed System. This requires that an operator be present regularly to measure and add the correct quantities of polymer and operate the mixer. The other concept is that for very small water treatment plants, the more automatic the chemical feed system the better, since available operator time may be very minimal. In addition, once an automatic system is set, there is no need to weigh dry chemical for each small batch, thus removing the potential for operator error. Another benefit of an automatic polymer system is that batches could be prepared several times per day, ensuring the use of a fresh effective polymer solution. Systems applicable to these two concepts are discussed following, and are referred to as Basic Polymer Feed Systems and Automatic Polymer Feed Systems.

BASIC POLYMER FEED SYSTEM

Introduction

Cost information is presented for two types of basic polymer feed systems. One system consists of a single tank used for mixing and storage, a mixer, and metering pump. The tank is sized to provide solution storage (at 0.25 percent) of the quantity of polymer required in one day, so that polymer only needs to be added once per day. The second system consists of two tanks (a mixing tank and a storage tank), a mixer, and metering pump. The mixing tank in the second system is elevated on a wooden stand to just above the top water level in the storage tank to allow gravity flow of mixed polymer solution into the storage tank. The storage tank is the same size as the mixing tank, since the transfer of aged polymer solution to the storage tank should only be required once per day.

A conceptual design of the basic polymer feed system using either one tank or two tanks is presented in Table 120. A typical system layout for the two tank basic polymer feed system is shown in Figure 112.

Construction Costs

Construction costs for the two types of basic polymer feed systems are based on the use of polyethylene mixing and storage tanks, gear driven, slow speed (420 rpm) mixers, and single head diaphragm metering pumps. The mixing tank is supported by a steel frame stand and the mixer is supported by a mixer mount which is attached to the stand. Pipe and valve costs for the single tank polymer feed system are the same as those used for the basic chemical feed system. Construction costs for the basic polymer feed system using one mixing tank are presented in Table 121 and Figure 113 for polymer feed capacities ranging from 0.3 to 4.7 kg/d (0.6 to 10.4 lb/day.).

TABLE 120. CONCEPTUAL DESIGNS FOR BASIC POLYMER FEED SYSTEM

	Maximum Chemical Feed Rate, lb/day				
	0.6	1.0	2.1	4.2	10.4
Dissolving Tank					
gal	30	50	100	200	500
Storage Tank*					
gal	30	50	100	200	500
Mixer, hp	1/4	1/4	1/4	1/3	1/3
Pump Capacity					
gal/hr	1.2	2.1	4.2	8.3	20.8
hp	1/8	1/8	1/8	1/4	1/4

*A separate storage tank was only used for the two tank polymer feed system.

TABLE 121. CONSTRUCTION COST SUMMARY FOR BASIC POLYMER FEED SYSTEM - SINGLE TANK

Cost Category	Maximum Polymer Feed Rate, lb/day 0.6	1.0	2.1	4.2	10.4
Mixing Tank	$ 290	$ 430	$ 640	$ 910	$1,830
Mixer	850	850	850	1,050	1,050
Metering Pump	640	700	700	1,230	1,600
Pipe and Valves	180	180	220	220	280
Labor, Installation	180	180	240	260	300
Electrical, Instrumentation	80	100	150	200	250
Subtotal	2,220	2,440	2,800	3,870	5,310
Design Contingencies	330	370	420	580	800
Total	$2,550	$2,810	$3,220	$4,450	$6,110

For the two tank basic polymer feed systems, the wooden stairway and platform used to elevate the mixing tank range between 0.9 m (3 ft) high for the smaller systems and 1.5 m (5 ft) high for the largest system. The mixing tank has a stand and mixer mount which are needed to support the mixer. Additional piping and valving is required to provide a transfer line and valve from the mixing tank to the storage tank. Construction costs for the basic polymer feed system with two tanks are shown in Table 122 and Figure 113.

TABLE 122. CONSTRUCTION COST SUMMARY FOR BASIC POLYMER FEED SYSTEM - TWO TANKS

Cost Category	Maximum Polymer Feed, lb/day 0.6	1.0	2.1	4.2	10.4
Mixing and Storage Tanks	$ 350	$ 540	$ 860	$1,270	$2,610
Wooden Stairs and Platform	480	480	480	610	690
Mixer	850	850	850	1,050	1,050
Metering Pump	640	700	700	1,230	1,600
Pipe and Valves	270	270	310	310	370
Labor, Installation	420	420	480	520	580
Electrical, Instrumentation	80	100	150	200	250
Subtotal	3,090	3,360	3,830	5,190	7,150
Design Contingencies	460	500	570	780	1,070
Total	$3,550	$3,860	$4,400	$5,970	$8,220

Operation and Maintenance Requirements and Costs

Operation labor requirements are primarily for daily measurement of dry polymer, adding it to the mixing tank, operating the mixer, and for the two tank system, transferring the polymer solution to the storage tank. Some additional labor is required for periodically checking the metering pump and for preventive maintenance and occasional repairs on the mixer and pump.

Electrical requirements are for the mixer and the metering pump. Mixer operation is assumed to be 30 minutes per day, while the polymer metering pump is assumed to operate continuously.

Maintenance material requirements are primarily for the mixer and metering pump. Total operation and maintenance requirements are summarized in Table 123 and are presented in Figures 114 and 115.

TABLE 123. OPERATION AND MAINTENANCE SUMMARY FOR BASIC POLYMER FEED SYSTEMS

Average Polymer Feed Rate, lb/day	Electrical Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.6	240	40	240	2,700
1.0	240	40	260	2,900
2.1	240	50	280	3,100
4.2	450	50	290	3,300
10.4	450	60	310	3,500

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

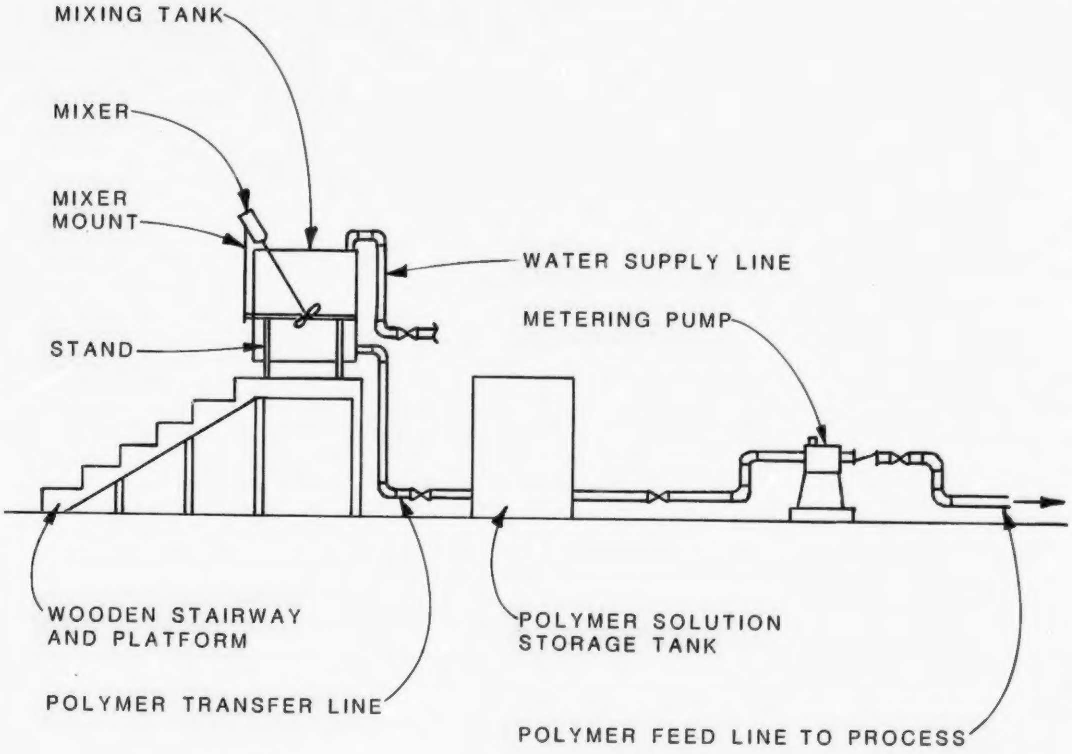

MIXING TANK
MIXER
MIXER MOUNT
WATER SUPPLY LINE
METERING PUMP
STAND
WOODEN STAIRWAY AND PLATFORM
POLYMER SOLUTION STORAGE TANK
POLYMER TRANSFER LINE
POLYMER FEED LINE TO PROCESS

Figure 112. Typical basic polymer feed system installation - two tanks.

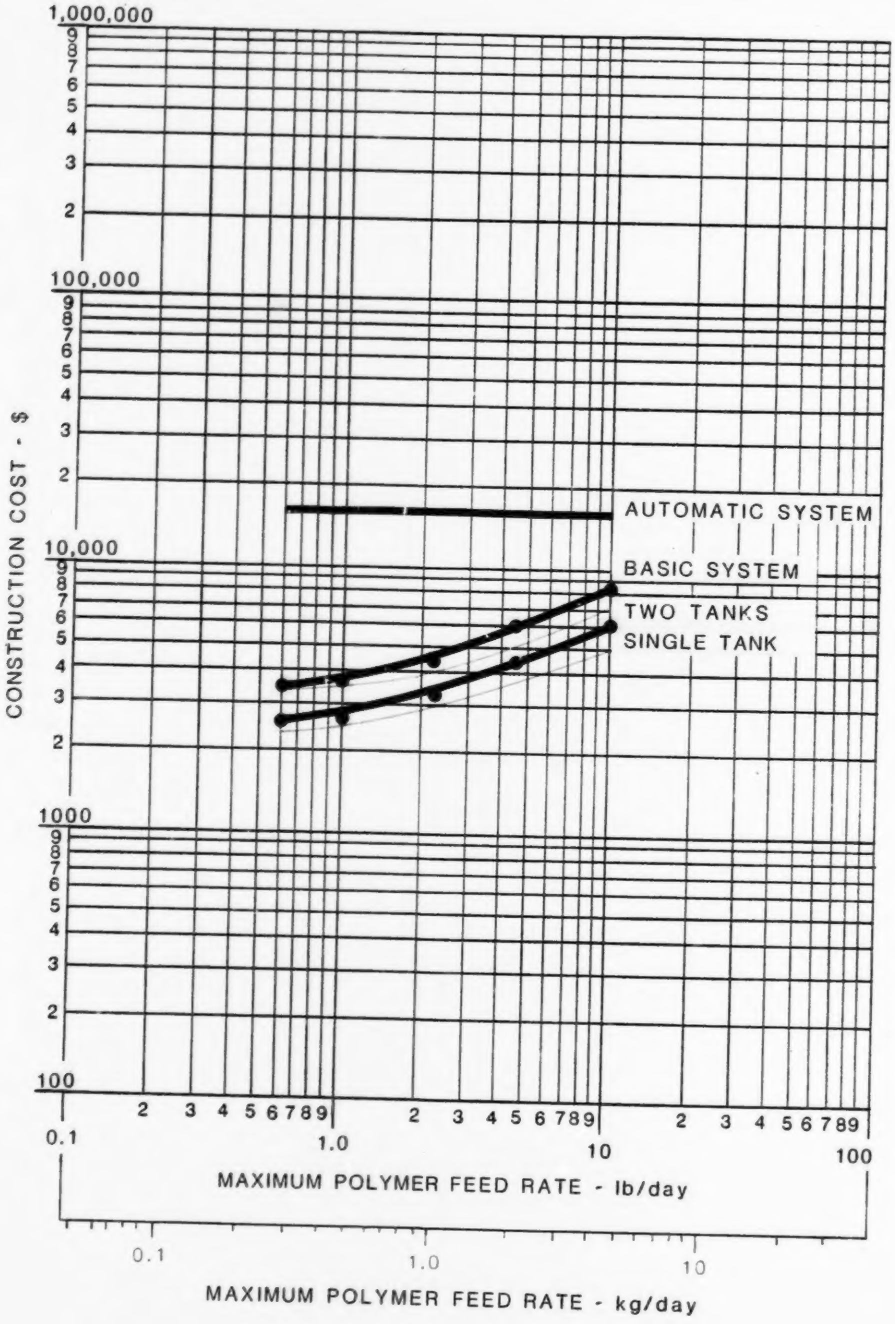


Figure 113. Construction cost for polymer feed systems.

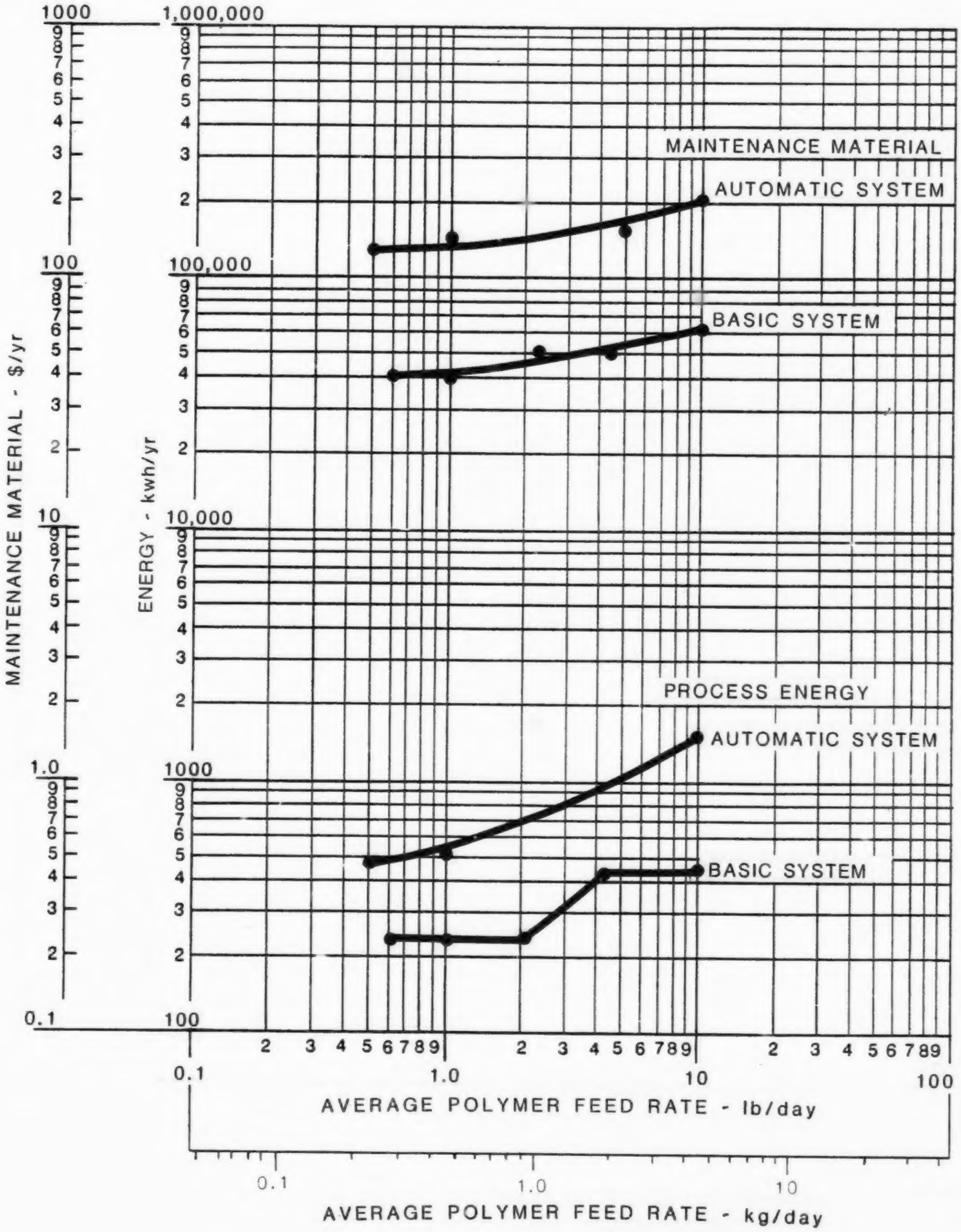


Figure 114. Operation and maintenance requirements for polymer feed systems - process energy and maintenance material.

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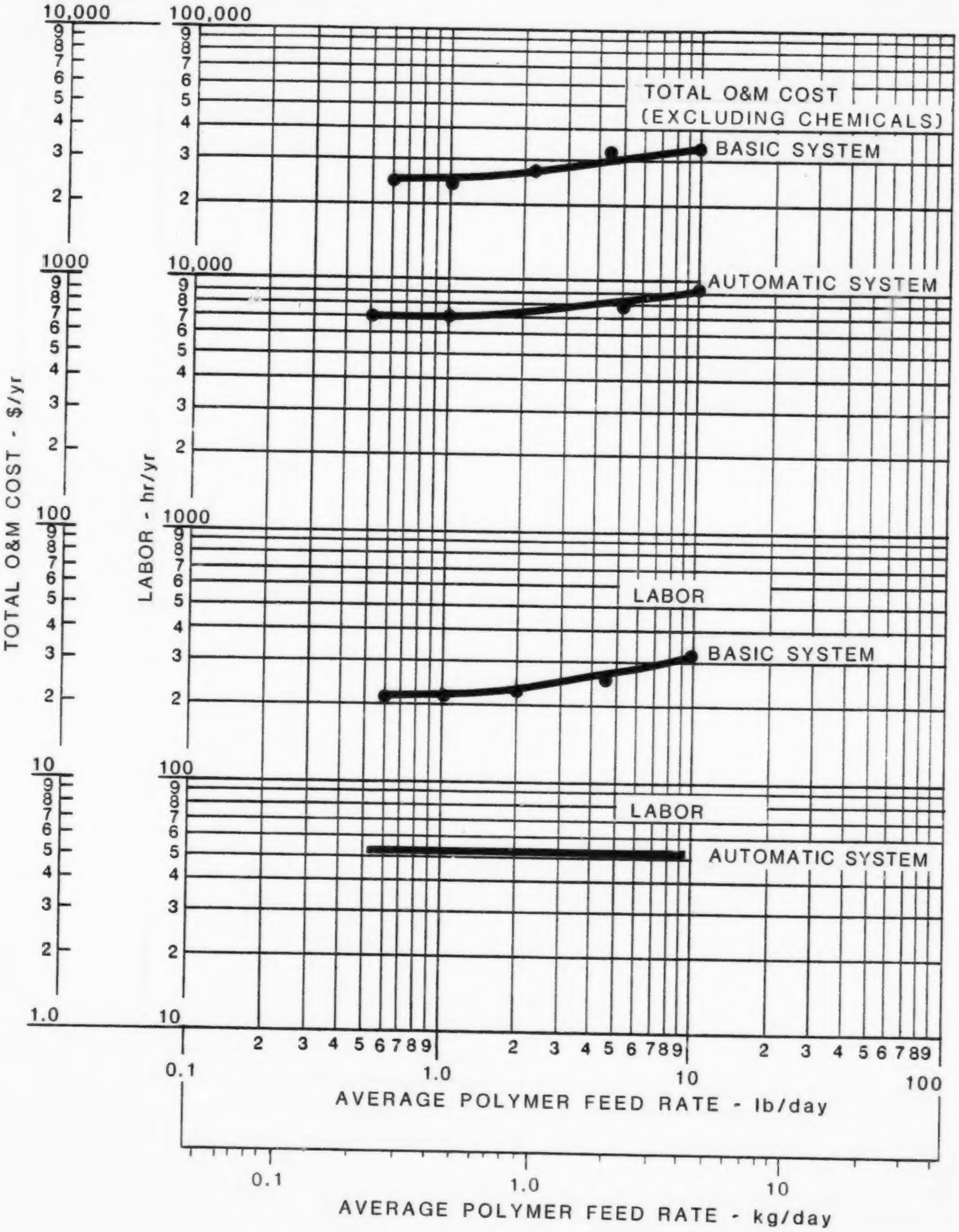


Figure 115. **Operation and maintenance requirements for polymer feed systems - labor and total O&M cost.**

AUTOMATIC POLYMER FEED SYSTEM

Construction Costs

Construction costs are for an automatic polymer feed system with a capacity ranging from 0.23 to 4.54 kg/d (0.5 to 10 lb/day), based upon a mixing/aging time of 30 minutes and a polymer solution concentration of 0.25 percent. A screw-type volumetric feeder automatically feeds dry polymer at a controlled rate into a wetting unit. The dry polymer feed rate is 0.022 m^3/hr (0.8 cu ft/hr). The wetted polymer is mixed in a 113 L (30 gal) mixing tank and the polymer solution is then transferred to a 151 L (40 gal) solution storage tank. A diaphragm metering pump with a capacity up to 79 L per hour (21 gal/hr) meters polymer solution to the point of application. All operations are automatically controlled or can be manually controlled from the control panel. These operations include: dry chemical feeding, wetting, and mixing; transfer of aged solution to the storage tank; and metering polymer solution to the process.

Construction costs for pipe and valves include a short pipeline for transferring metered polymer solution to the application point, a water supply pipe, and a drain pipe. Construction costs for a complete automatic polymer feed system are shown in Table 124 and Figure 113.

TABLE 124. CONSTRUCTION COST SUMMARY FOR AUTOMATIC POLYMER FEED SYSTEM

Cost Category	Cost
Manufactured Equipment	$ 12,200
Labor, Installation	320
Pipe and Valves	280
Electrical, Instrumentation	640
Subtotal	13,440
Design Contingencies	2,020
Total	$ 15,460

Operation and Maintenance Requirements and Costs

Operation labor requirements for the automatic polymer feed system include checking the system for proper operation, filling the hopper with dry polymer (ranges from every 8 days to every 30 days), and for occasional preventive maintenance of the feed system.

Electrical requirements include operation of the dry polymer feeder, the mixer, and the polymer solution metering pump. The dry feeder has a 0.12 kw (1/6 hp) motor which is operated about 1.0 minute per cycle; a cycle is a 114 L (30 gal) batch of polymer solution. There are a maximum of 15 cycles per day for the system operated at 4.5 kg/d (10 lb/day). The mixer has a 0.37 kw (1/2 hp) motor and is operated 30 minutes per cycle. The solution metering pump has a 0.19 kw (1/4 hp) motor which is assumed to operate continuously. Electrical energy requirements are higher for this automatic polymer feed system than for the basic chemical feed system primarily because the polymer solution is fed at a much more dilute concentration of only 0.25 percent. There is, therefore, more mixing and pumping required per pound of chemical fed.

Maintenance material requirements are primarily for the dry feeder, mixer, and metering pump. Total operation and maintenance requirements are summarized in Table 125 and Figures 114 and 115.

TABLE 125. OPERATION AND MAINTENANCE SUMMARY FOR AUTOMATIC POLYMER FEED SYSTEMS

Average Polymer Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.5	460	130	50	700
1	520	150	50	700
5	950	170	50	800
10	1,500	200	50	900

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

POWDERED ACTIVATED CARBON FEED SYSTEMS

Introduction

Powdered activated carbon (PAC) is used in water treatment plants primarily for taste and odor control. Recently however, PAC has also been used in some instances for removal of trihalomethane (THM) precursor material, in systems having seasonal difficulty in meeting the THM MCL.

PAC is a finely ground, insoluble black powder which will create dust problems in a plant if no method of dust control is used. PAC feed systems must provide a method of wetting and slurrying the carbon, maintaining the slurry, and proportionally metering, or feeding, the slurry to the water at the point of application. The concentration of the PAC slurry is generally about 0.12 kg/L (1.0 lb/gal). Powdered carbons used in water treatment have bulk densities which typically range from 449 to 769 kg/m^3 (28 to 48 lb/ cu ft). Small systems usually purchase PAC in bags weighing between 22.7 and 27.2 kg (50 and 60 lb).

Impact of Raw Water Quality on Treatment Cost

The required PAC dosage for taste and odor control depends entirely on the water being treated. In a survey of 137 municipalities using PAC, the average dosage was 2.8 mg/L, the high 5.1, and the low 0.5 mg/L.[1] For removal of organic compounds such as THM precursors or volatile organic compounds (VOCs), higher PAC doses are needed. A maximum dose of 30 mg/L was assumed for these cost estimates. Therefore, the largest feed system considered herein is 113 kg/d (250 lb/day), based on 30 mg/L for a maximum plant flow of 3,785 m^3/d (1 mgd).

Construction Costs

PAC feed systems for small water plants can vary greatly in design, depending upon the method of feeding, level of automation, dependability, and maintenance requirements included in the design. Well-designed PAC feed systems are generally equipped with dust control facilities, because of the powdery, sooty nature of PAC. The type of PAC feed system often found in the smallest plants consists of a tank, a mixer and a slurry metering pump. Major dust problems are usually associated with these feed systems. However, due to the expense of installing a dust control system, many small utilities will continue to operate with the PAC dust problems.

Conceptual designs for the three types of PAC feed systems are presented in Table 126. These three types of systems represent varying degrees of sophistication, operational simplicity, and methods of controlling PAC dust. The three systems are subsequently referred to in the text, tables and figures as follows:

Simple slurry pump system, no dust control.
Dry feeder system with dust collector.
Slide gate/slurry pump system with dust collector.

TABLE 126. CONCEPTUAL DESIGNS FOR POWDERED ACTIVATED CARBON FEED SYSTEMS

	Maximum Feed Rate, lb/day of PAC		
	50	250	250
Cost Category	Simple Slurry Pump	Dry Feeder*	Slurry Pump**
Storage Hopper, cu ft	--	10	10
Bag Loading Hopper, number	--	1	1
Dust Collector, hp	--	3/4	3/4
Dry Feeder, maximum cu ft/hr	--	4.0	--
Dry Feeder, hp	--	1/4	--
Mixing Tank, gal	60	35	275
Mixer, hp	1/4	1/4	3/4
Slurry Pump, gal/hr	2.1	--	10
Slurry Pump, hp	1/4	--	1/4

Notes: *Dry Feeder System with gravity flow of PAC slurry to point of application.
**Slurry Pump System with slide gate to control PAC addition to mixing tank.

The first of these is a relatively simple system with a maximum feed capacity of 23 kg/d (50 lb/day), while the latter two are larger and have maximum feed rates of 113 kg/d (250 lb/day). Typical layouts for each of these three systems are show in Figure 116.

The "simple slurry pump system, no dust control" consists of a polyethylene mixing tank on a steel frame tank stand, a mixer supported by a mixer mount attached to the stand, and a slurry metering pump. For systems greater than this size, dust control facilities are considered to be essential. The maximum feed capacity of this simple system is 23 kg/d (50 lb/day).

For systems with PAC feed capacities of up to 113 kg/d (250 lb/day), two types of PAC feed systems are shown in Table 126. Both systems include a bag loading hopper with a dust collector, a 1.2 m (4 ft) high wooden stairway, and 0.28 m^3 (10 cu ft) of hopper storage. At a PAC density of 481 kg/m^3 (30 lb/cu ft), this amounts to a hopper storage capacity of 136 kg (300 lb). The "dry feeder system with dust collector" consists of the bag loading hopper, dust collector, screw type dry chemical feeder, mixing tank, and gravity flow of the carbon slurry to the point of application. The rate of carbon feed to the application point is controlled by the dry feeder, while the rate of water flow to the mixing tank is controlled by a manually operated flow control valve. The mixing tank has a capacity of only 132 L (35 gal); this volume is sufficient since the dry feeder is automatic. Operator attention is minimal, since the hopper must only be filled once per day.

This dry feeder system for PAC differs from the Dry Chemical Feed Systems presented previously, because the dry feeder system for PAC is expressly designed to feed powdered activated carbon. Key additions required in the PAC system are a bag loading hopper and dust collector, as well as explosion proof motors for the dry feeder, dust collector, and mixer.

The "slide gate/slurry pump system with dust collector" includes a slide gate to manually control PAC addition to a mixing tank and a slurry pump to meter PAC slurry to the point of application. The mixing tank for the slurry pump system is 1,040 L (275 gal), which is much larger than the mixing tank used for the dry feeder system. The larger mixing tank is necessary since PAC addition to the mix tank is performed only once per day. Thus, slurry is prepared on a batch basis and fed on a continuous basis in the slide gate/slurry pump system, in contrast to the dry chemical feeder which both prepares and feeds the PAC slurry on a continuous basis.

Due to the fire and explosion potential of PAC dust, cost estimates for motors required for mixers, pumps, dry feeders and dust collectors are based upon the use of totally enclosed explosion proof construction. Construction costs are presented in Table 127 and Figure 117.

TABLE 127. CONSTRUCTION COST FOR POWDERED ACTIVATED CARBON FEED SYSTEMS

	Maximum Feed Rate, lb/day of PAC		
	50	250	250
Cost Category	Simple Slurry Pump	Dry Feeder	Slurry Pump
Storage Hopper	$ --	$ 800	$ 800
Loading Hopper and Dust Collector	--	1,440	1,440
Wooden Stairway	--	300	300
Slide Gate	--	--	220
Dry Feeder	--	3,380	--
Mixing Tank	430	610	1,020
Mixer	360	570	620
Slurry Pump	1,480	--	1,480
Pipe and Valves	180	280	280
Labor, Installation	190	710	760
Electrical, Instrumentation	150	300	350
Subtotal	2,790	8,390	7,270
Design Contingencies	420	1,260	1,090
Total	$3,210	$9,650	$8,360

Operation and Maintenance Requirements and Costs

Operation labor requirements for the PAC feed system include labor for: adding water to the mixing tank for the smaller system before adding any carbon; opening bags of PAC and emptying them into the mixing tank, or hopper for the larger systems; turning on the dust collector when bag loading begins and turning it off when bag loading is over; shaking the cloth filters in the dust collector with a foot pedal to remove PAC dust and occasional replacement of the filters; opening the slide gate to feed PAC into the large mixing tank for the slurry pump system; occasional preventive maintenance of the mixer, pump and dry feeder; spot checking and calibration of the dry feeder and slurry pump; and occasionally cleaning up PAC dust which has gotten onto the floor and walls. Of the two large systems with hopper storage of PAC, the slurry pump system requires more labor primarily due to the required gradual opening of the slide gate to control PAC addition to the mixing tank.

Electrical requirements are for the mixer, slurry pump, dry feeder, and dust collector; motor horsepower requirements are shown in Table 126. The mixer, slurry pump, and dry feeder are assumed to operate continuously, 24 hours per day. The dust collector is operated only when bags of PAC are being emptied into the bag loading hopper, a total of 30 minutes per day for the 113 kg/d (250 lb/day) system. The electrical energy requirement for the slurry pump PAC feed system is higher than for the dry feeder system because of the larger mixing/slurry tank and larger, more powerful mixer.

Maintenance material requirements are for the mixer, slurry pump, dry feeder, and dust collector. The maintenance material requirement for the dry feeder system is more than for the slurry pump system due to the higher capital cost of equipment in the dry feeder system. Operation and maintenance requirements are summarized in Table 128 and Figures 118 and 119.

TABLE 128. OPERATION AND MAINTENANCE SUMMARY FOR POWDERED ACTIVATED CARBON FEED SYSTEMS

Average PAC Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
50 Simple Slurry Pump	2,040	70	155	1,900
250 Dry Feeder System	3,360	150	300	3,700
250 Slurry Pump System	5,400	120	395	4,800

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

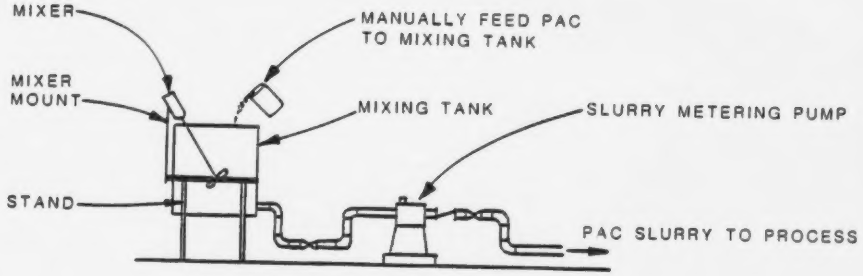
When purchased in 22.7 kg (50 lb) bags, powdered activated carbon typically costs $1.32/kg ($0.60/lb). To calculate the PAC cost, the following formula may be used:

$$\$/\text{day} = \text{gal/day (mg/L of PAC)} (5.004\times10^{-6})$$

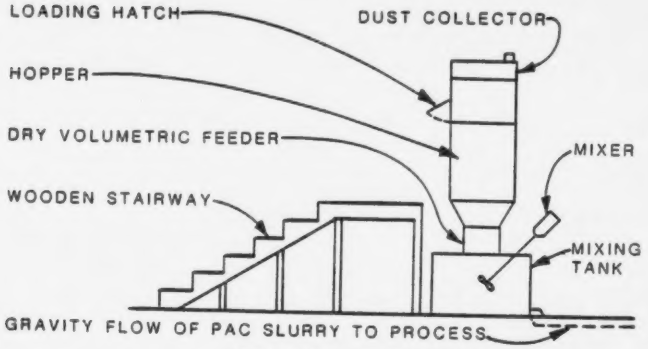
where gal/day represents the average daily flow of water treated with PAC.

References

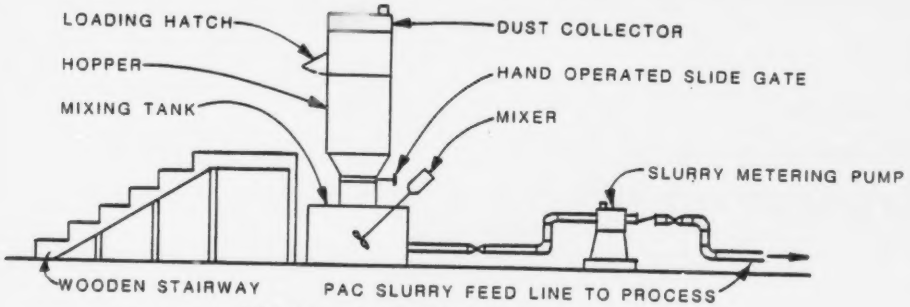
1. Sanks, R. L., Editor, "Water Treatment Plant Design for the Practicing Engineer," Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1978, p. 492.


MIXER
MANUALLY FEED PAC TO MIXING TANK
MIXER MOUNT
MIXING TANK
SLURRY METERING PUMP
STAND
PAC SLURRY TO PROCESS

50 lb/day SYSTEM
POWDERED ACTIVATED CARBON FEED SYSTEM


LOADING HATCH
DUST COLLECTOR
HOPPER
DRY VOLUMETRIC FEEDER
MIXER
WOODEN STAIRWAY
MIXING TANK
GRAVITY FLOW OF PAC SLURRY TO PROCESS

250 lb/day DRY FEEDER
POWDERED ACTIVATED CARBON FEED SYSTEM


LOADING HATCH
DUST COLLECTOR
HOPPER
HAND OPERATED SLIDE GATE
MIXING TANK
MIXER
SLURRY METERING PUMP
WOODEN STAIRWAY
PAC SLURRY FEED LINE TO PROCESS

250 250 lb/day SLURRY PUMP
POWDERED ACTIVATED CARBON FEED SYSTEM

Figure 116. Typical powdered activated carbon feed system installations

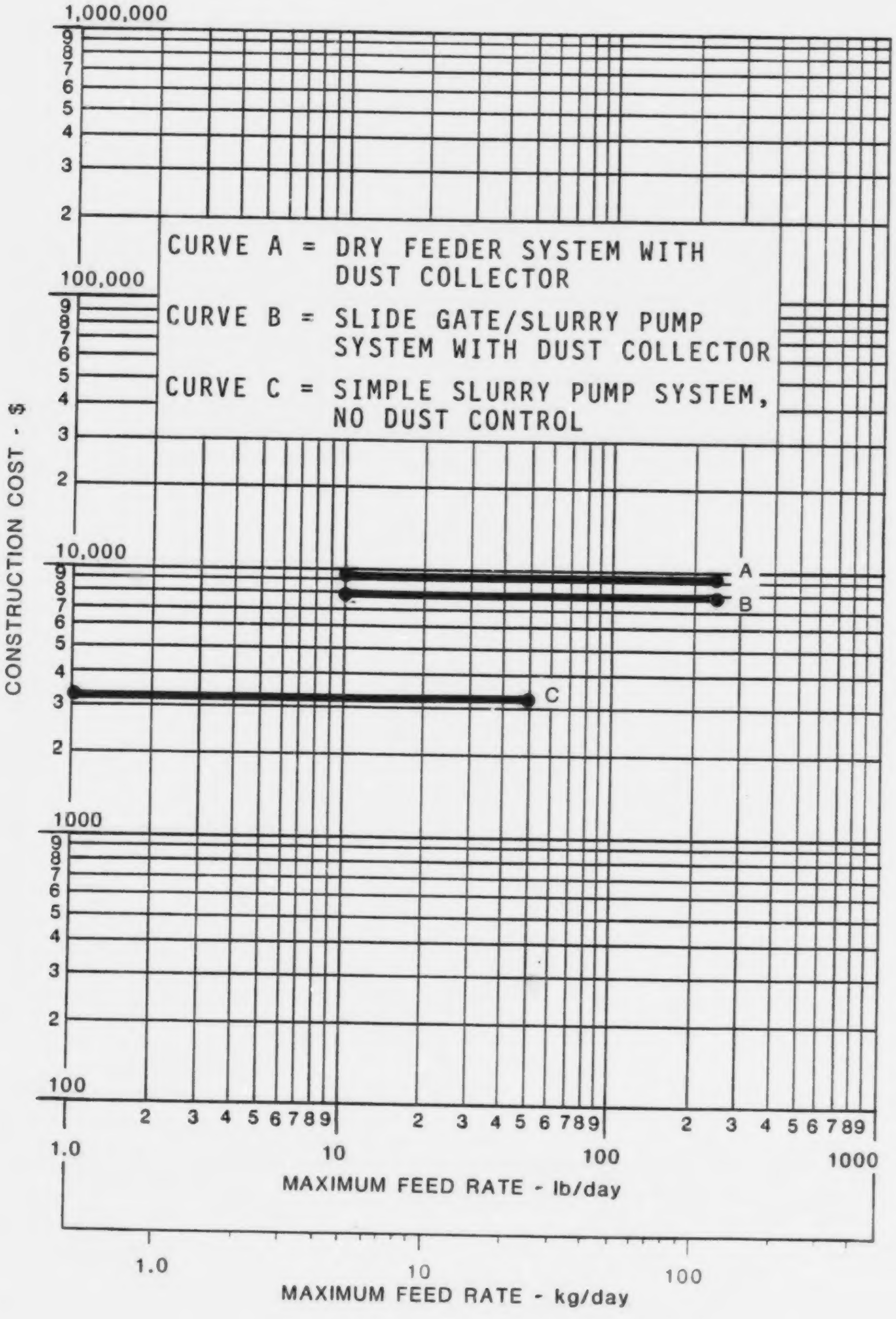


Figure 117. Construction cost for powdered activated carbon feed systems.

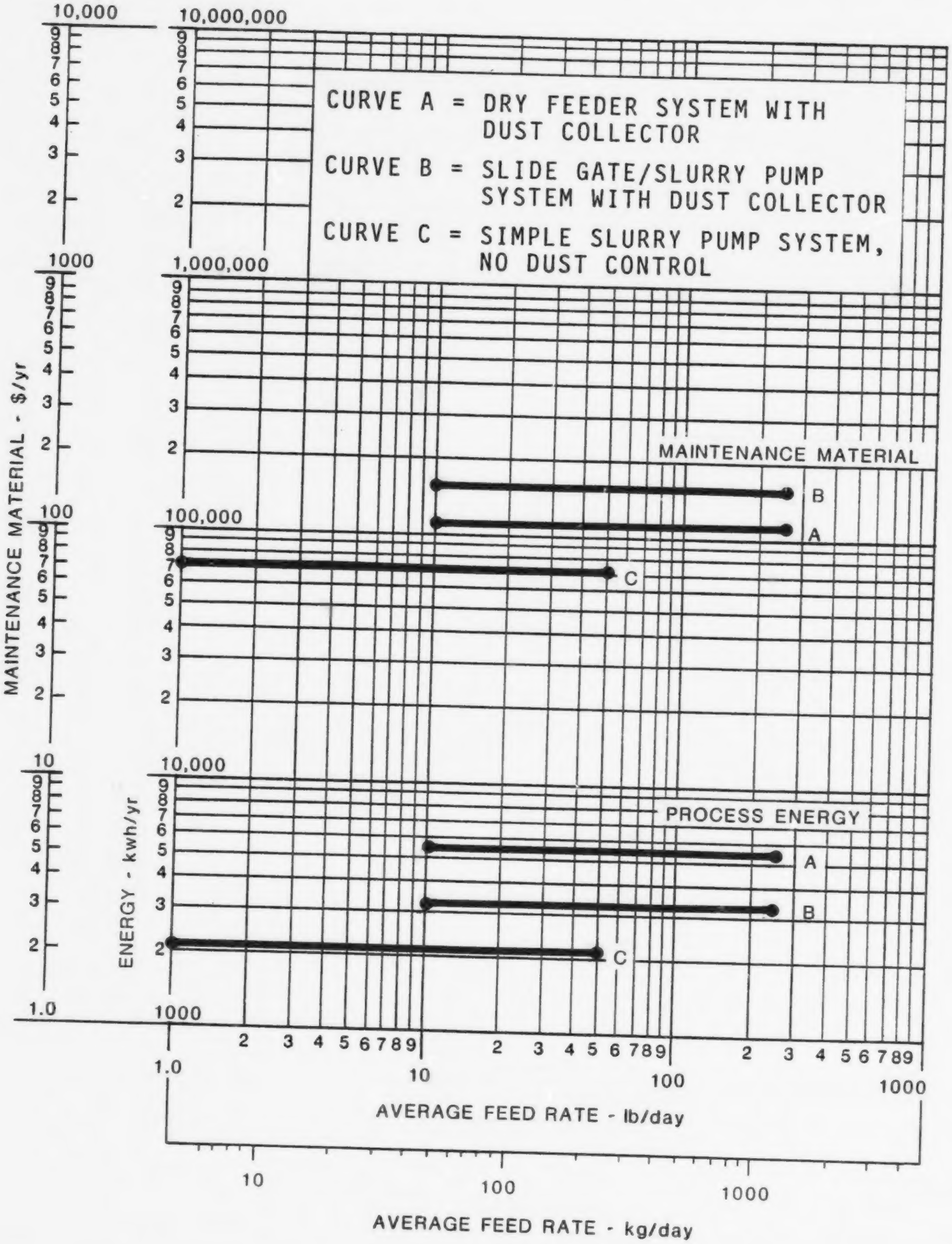


Figure 118. Operation and maintenance requirements for powdered activated carbon feed systems - process energy and maintenance.

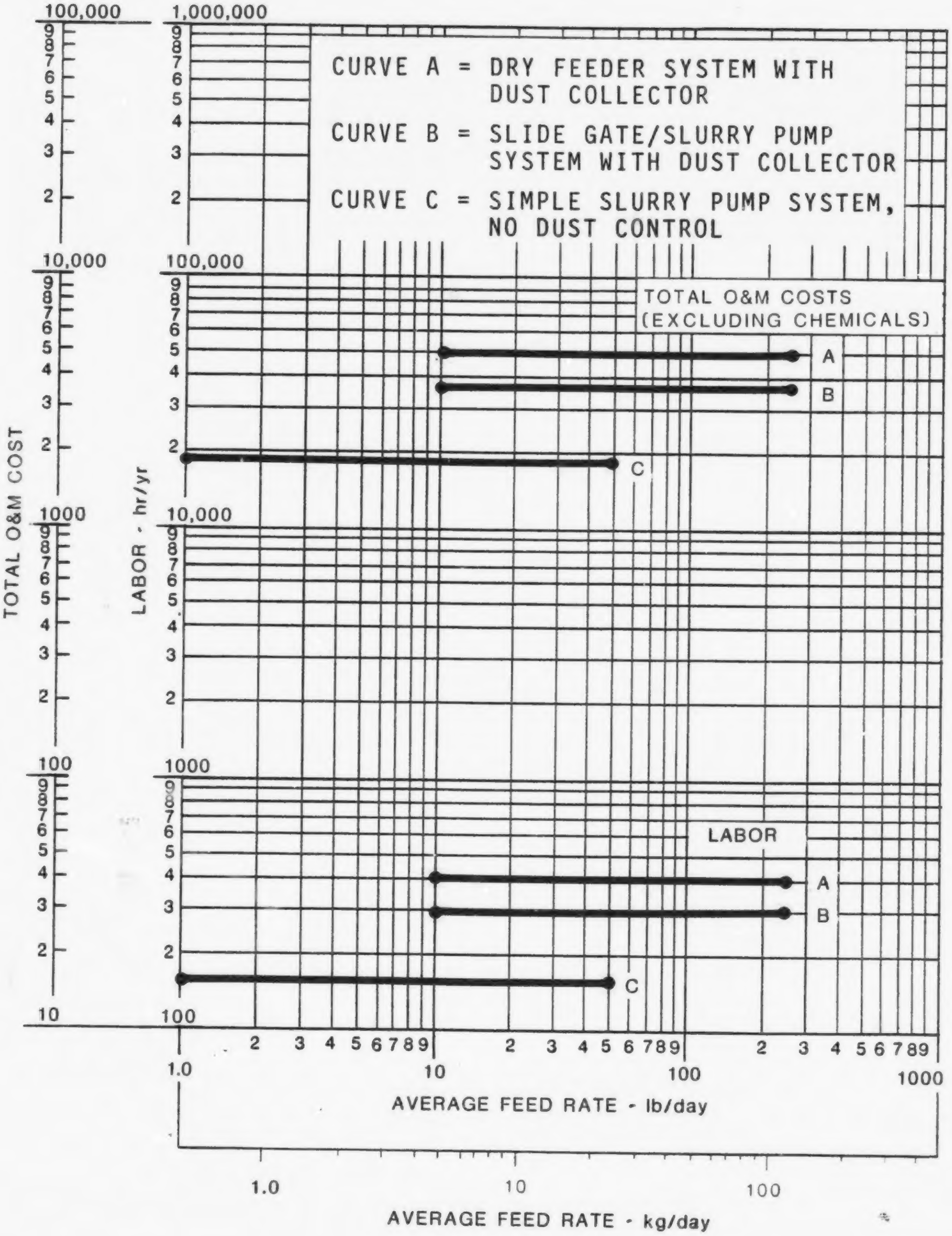


Figure 119. **Operation and maintenance requirements for powdered activated carbon feed systems - labor and total O&M cost.**

SULFURIC ACID FEED SYSTEMS

Introduction

Sulfuric acid is commonly available in the following solution strengths:

- 98-99% H_2SO_4
- 66° Baume (93.2% H_2SO_4)
- 60° Baume (77.7% H_2SO_4)
- 50° Baume (62.2% H_2SO_4)

Sulfuric acid is the most commonly used acid in water treatment applications. Typically it is used for pH adjustment, such as before reverse osmosis or activated alumina treatment.

The most common strength of sulfuric acid used in the water treatment industry is the 66° Baume acid (93.2% H_2SO_4). This concentration of acid was used in the conceptual design for the sulfuric acid feed system. There are several advantages to purchasing and using concentrations of 93% or greater. First, transportation, storage, and pumping costs are less when a concentrated form is used. Second, sulfuric acid is not corrosive to cast iron or steel at a 93% concentration, while it is corrosive to these materials when diluted. Materials such as PVC, Teflon, Viton, and polyethylene are acceptable for both concentrated and dilute sulfuric acid. Third, sulfuric acid addition to water is an exothermic (heat releasing) reaction, which can cause splattering of hot acid if the acid is added too rapidly to the water. Using concentrated acid directly eliminates this problem. Fourth, direct use of concentrated acid eliminates the need for acid dilution in a dilution tank. If this step is used, it represents a potential safety hazard due to the exothermic (heat releasing) reaction which occurs during dilution.

Construction Costs

A conceptual design for sulfuric acid feed systems is presented in Table 129, and typical system layouts are shown in Figure 120. For the three smallest systems, acid is delivered in 18.9 or 49 L (5 or 13 gal) carboys or 208 L (55 gal) drums. A hand pump is then used to transfer acid to the feed tank, and a metering pump is used to pump acid to the process at a predetermined rate. In the larger systems, acid is delivered in bulk to a storage tank, which is sized to hold a minimum of 21 days acid requirement. Gravity flow is used to transfer acid to a smaller feed tank, from which the metering pump draws acid. The feed tank is sized to hold a minimum of three days acid requirement.

Construction costs for the sulfuric acid feed system are summarized in Table 130 and are presented in Figure 121. The costs for acid storage and feed tanks are based on using covered polyethylene tanks. The larger two systems with storage tanks of 2,270 and 4,540 L (600 and 1,200 gal) also include a 0.9 m (3 ft) high wooden stairway to enable operators to reach the top of the 2.1 m (7 ft) high acid storage tank. The largest polyethylene tank of 4,540 L (1,200 gal) has a steel banded wooden girdle around the tank which provides additional support and strength. This factor of safety is needed due to the high specific gravity of 1.83 kg/L (15.3 lb/gal) and hazardous nature of the

TABLE 129. CONCEPTUAL DESIGNS FOR SULFURIC ACID FEED SYSTEMS

	Maximum Feed Rate, lb/day of H_2SO_4						
	0.8	4	8	42	83	417	834
Carboy or Drum gal	5	13	55	---	---	---	---
Storage Tank gal	---	---	---	100	200	600	1,200
Manual Transfer Pumps number	1	1	1	---	---	---	---
Feed Tank gal	6	12	12	30	30	100	200
Metering Pump gal/hr	.0024	.012	.024	.12	.24	1.2	2.4

Notes: 1. Feed tank low level alarm and pH controller are additional items which may be desired in some feed systems.
2. Density of 66° Baume sulfuric acid is 15.3 lb/gal.

TABLE 130. CONSTRUCTION COST SUMMARY FOR SULFURIC ACID FEED SYSTEMS

	Maximum Feed Rate, lb/day of $H_2 2SO_4$						
Cost Category	0.8	4	8	42	83	417	834
Storage and Feed Tanks	$ 60	$ 80	$ 80	$ 310	$ 450	$1,110	$2,400
Wooden Stairway	---	---	---	---	---	300	300
Manual Transfer Pumps	100	100	100	---	---	---	---
Pipe and Valves	320	320	320	480	480	540	540
Metering Pump	410	410	410	430	430	710	870
Containment Wall and Crushed Limestone	180	180	280	310	480	880	1,480
Labor, Installation	320	320	320	420	460	640	730
Electrical	80	80	80	100	100	120	120
Subtotal	1,470	1,490	1,590	2,050	2,400	4,300	6,440
Design Contingencies	220	220	240	310	360	640	970
Total	$1,690	$1,710	$1,830	$2,360	$2,760	$4,940	$7,410

Note: Depending on the desired complexity, a low level alarm on the acid feed tank can be installed for an additional $600. A pH controller to control acid feed rate delivered by the pump can be installed for about $1,500.

sulfuric acid. A concrete wall and layer of crushed limestone are provided around the storage tank to completely contain any spill of acid due to rupture or leakage from the tank. The concrete containment wall around the storage tank is 20.3 cm (8 in) thick cast-in-place concrete and varies in height between 0.3 and 0.45 m (1.0 and 1.5 ft). The crushed limestone layer is 0.15 m (0.5 ft) deep around the tank inside the containment wall.

The pumps are electronic chemical metering pumps which use a D.C. solenoid and solid state pulsing circuit rather than a conventional motor and gearbox assembly. Wetted parts of the pump are constructed of the following materials: fittings and head are PVC; valve balls are ceramic; and elastomers are Viton. Pipe and valve costs allow for a minimum of 6.1 m (20 ft) lengths of 2.5 cm (1 in) PVC water supply, 3.9 cm (1 1/2 in) polypropylene drain pipe, and 2.5 cm (1 in) PVC acid transfer and feed pipe. It was assumed that two drain lines are provided for feed systems with capacities larger than 3.6 kg per day (8 lb per day), one for the storage tank and one for the feed tank.

Operation and Maintenance Requirements and Costs

Operation labor requirements include labor for transferring acid from the storage tank to the feed tank using a manual hand pump for the smallest system and by opening and closing a valve in the gravity transfer line for the larger systems. Other labor functions include ordering and receiving deliveries of carboys, drums, and bulk shipments of acid, checking and calibrating the metering pump, maintenance and repair of the pump and PVC feed lines and valves, and cleaning up infrequent leaks and spills of acid.

Electrical requirements are for the metering pump which is assumed to operate continuously, 24 hours per day. Maintenance material costs are primarily for the metering pump, although some material costs are included for piping and valves which may need occasional repair or replacement. Operation and maintenance requirements are summarized in Table 131 and Figures 122 and 123.

TABLE 131. OPERATION AND MAINTENANCE SUMMARY FOR SULFURIC ACID FEED SYSTEMS

Average Chemical Feed Rate, lb/day	Process Energy, kwh/hr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.8	42	50	110	1,300
4	42	50	130	1,500
8	42	50	150	1,700
42	42	70	160	1,800
83	60	80	170	2,000
417	175	130	210	2,500
834	380	160	220	2,600

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

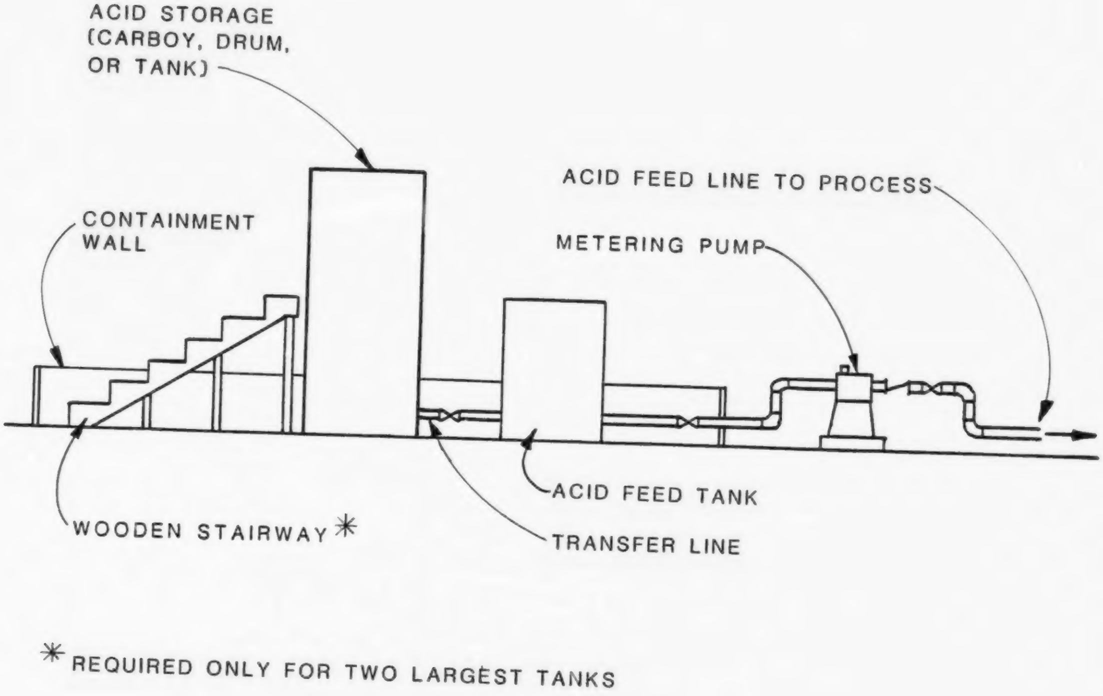

ACID STORAGE
(CARBOY, DRUM, OR TANK)
ACID FEED LINE TO PROCESS
CONTAINMENT WALL
METERING PUMP
ACID FEED TANK
WOODEN STAIRWAY *
TRANSFER LINE
* REQUIRED ONLY FOR TWO LARGEST TANKS

Figure 120. Typical sulfuric acid feed system installation.

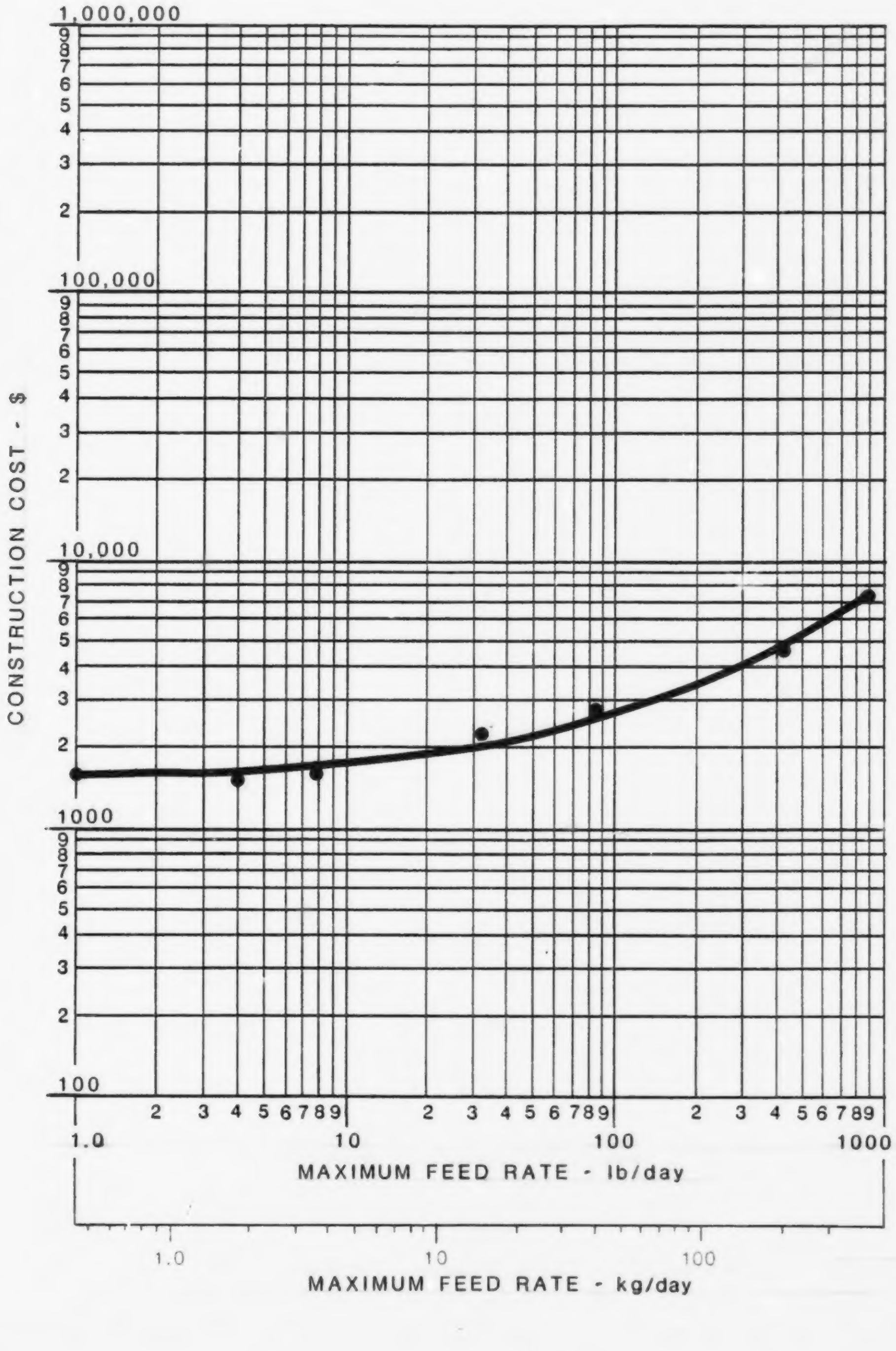


Figure 121. Construction cost for sulfuric acid feed systems.

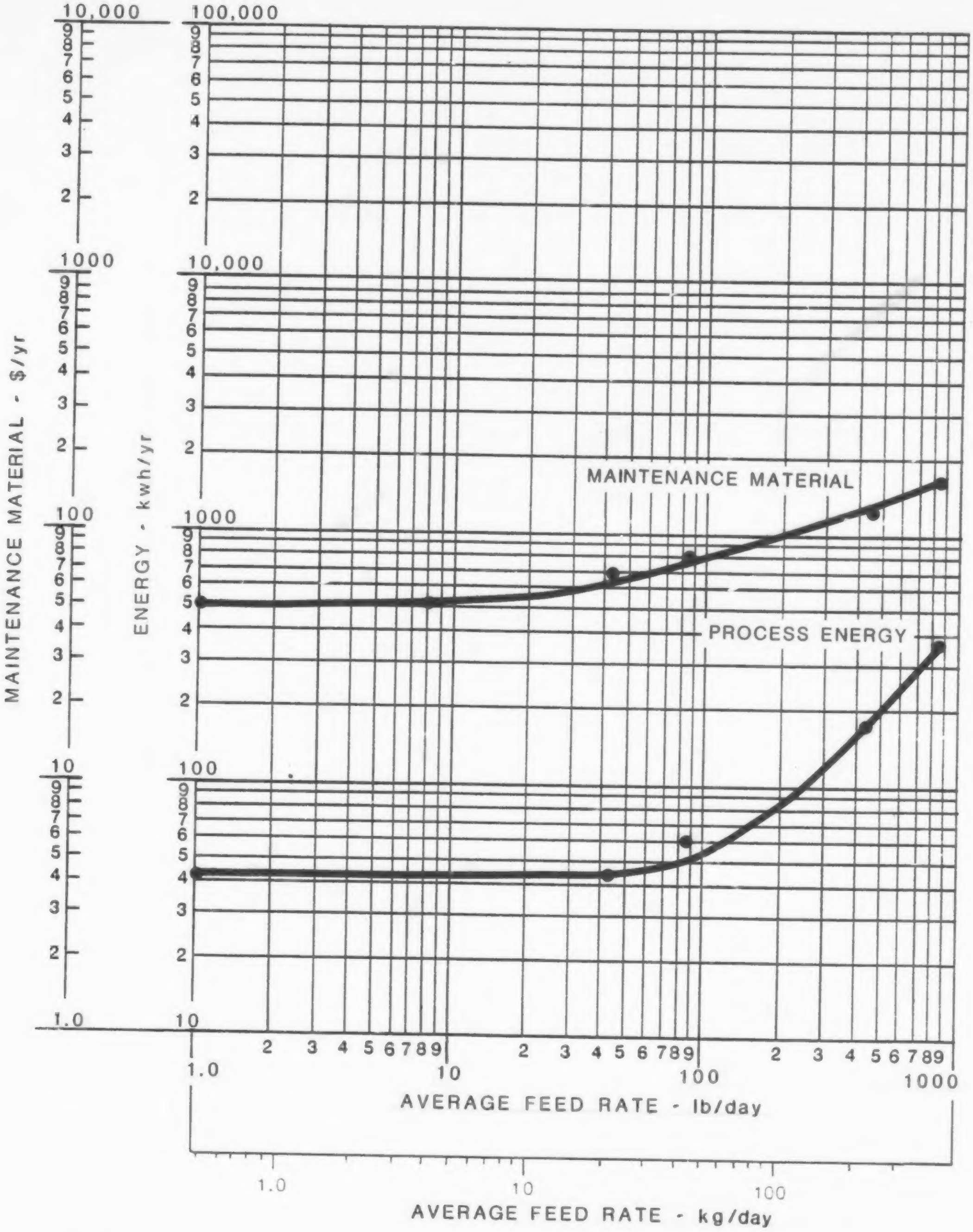


Figure 122. **Operation and maintenance requirements for sulfuric acid feed systems - process energy and maintenance material.**

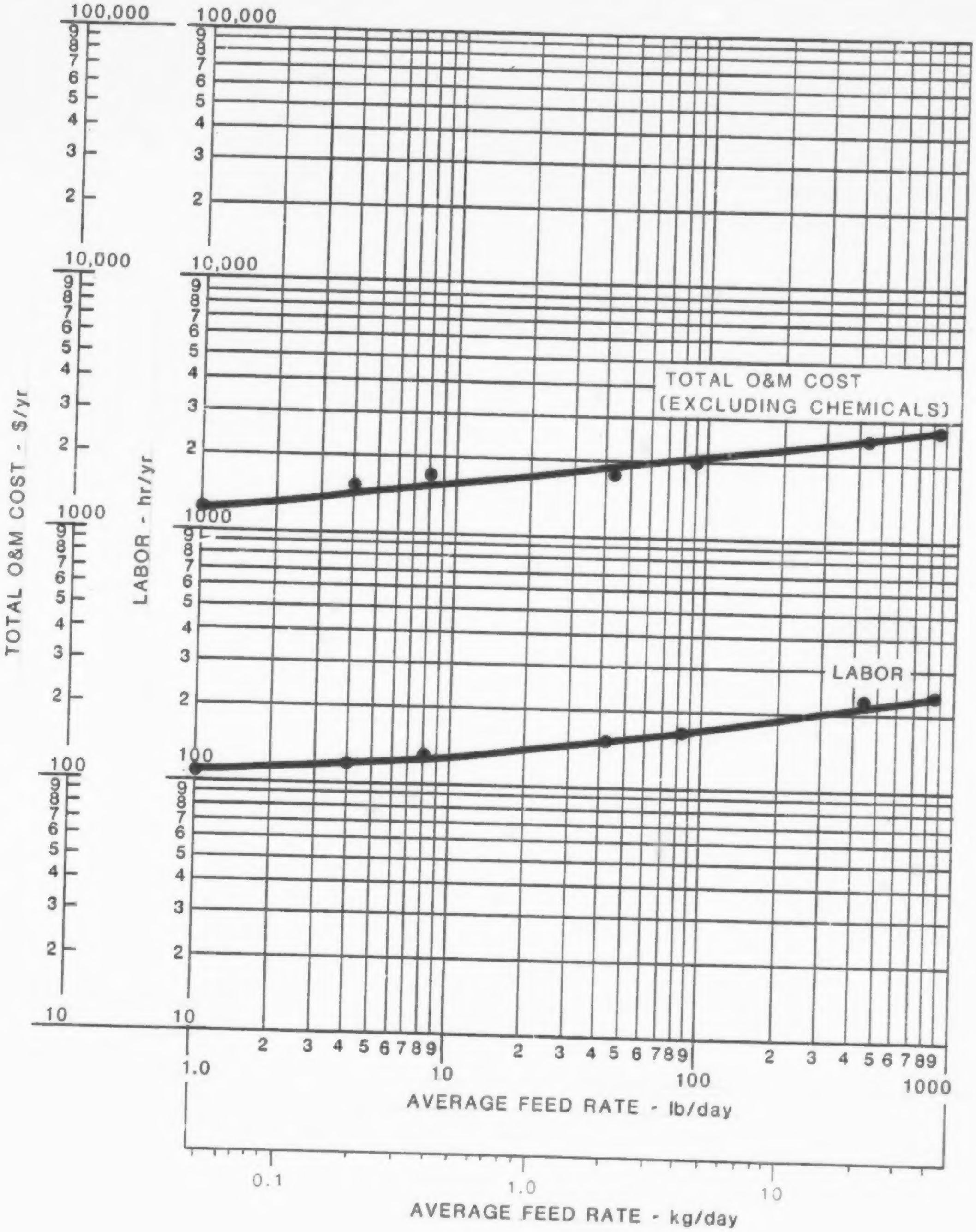


Figure 123. **Operation and maintenance requirements for sulfuric acid feed systems - labor and total O&M cost.**

SODIUM HYDROXIDE FEED SYSTEMS

Introduction

Sodium hydroxide, also frequently called caustic soda, is commonly available as 50 percent NaOH, although 73 percent NaOH may also be available. Solutions of sodium hydroxide which are more dilute than 50 percent NaOH are also sometimes available, but the availability varies widely from location to location. A 50 percent NaOH solution was assumed in the conceptual design of this chemical feed system.

At a 50 percent concentration, sodium hydroxide solution will begin to crystallize at 12°C (54°F). Because of this characteristic, 50 percent sodium hydroxide solutions are either stored in a heated building, in heated insulated storage tanks, or they are diluted upon delivery. The freezing point of 20 percent NaOH is less than -18°C (0°F). Dilution of sodium hydroxide from 50 percent to 20 percent releases a great deal of heat, which could cause the splattering of hot caustic if done too rapidly. Because of the difficulty and potential danger associated with the dilution of sodium hydroxide, and because of the additional volumes which require pumping and storage, it is assumed in this analysis that 50 percent NaOH solution is stored and fed. Smaller storage tanks would be located in a heated building and large storage tanks would be located outdoors, but would be insulated and heated. A mixer is also included for the large storage tanks to be used during cold weather to keep the temperature uniform and prevent partial freezing.

Construction Costs

A conceptual design for sodium hydroxide feed systems is presented in Table 132, and typical system layouts are shown in Figure 124. The basic system includes a storage tank which ranges in size from an 18.9 L (5 gal) carboy up to a 9,460 L (2,500 gal) storage tank. The storage tank is sized to hold a minimum volume of 18 days of storage. For the smaller systems a manual hand pump is used to transfer caustic soda from the 18.9 and 49 L (5 and 13 gal) carboys and the 208 L (55 gal) drum to a a small feed tank. The carboys and drum are provided by the chemical distributor. The feed tank is sized to be able to hold at least 2.5 days usage of caustic soda.

For the larger systems, the caustic soda is transferred by gravity flow in a PVC line from the storage tanks to the feed tank. The feed tanks for each system are located indoors in a heated building. A metering pump is used to pump sodium hydroxide from the feed tank to the process at a predetermined rate. A containment wall surrounding the storage tank, feed tank, and metering pump is provided which can hold the entire quantity of sodium hydroxide in the event of a spill or leak.

Construction costs are for a sodium hydroxide feed system with feed capacities ranging from 0.4 to 378 kg/d of NaOH (0.8 to 834 lb/day). Construction costs are summarized in Table 133 and are presented in Figure 125. The costs for caustic soda storage and feed tanks are based on using covered polyethylene tanks, and the costs for heating and insulation for storage tanks of 757 L (200 gal) and larger are for electrical heat tracing and fiberglass

TABLE 132. CONCEPTUAL DESIGNS FOR SODIUM HYDROXIDE FEED SYSTEMS

	Maximum Feed Rate, lb/day of NaOH						
	0.2 to 0.8	4	8	42	83	417	834
Carboy or Drum gal	5	13	55	---	---	---	---
Storage Tank gal	---	---	---	200	500	1,200	2,500
Heater, watts	---	---	---	840	2,100	5,000	10,500
Mixer, hp	---	---	---	1/4	1/2	3/4	1 1/2
Manual Transfer Pump, number	1	1	1	---	---	---	---
Feed Tank gal	6	12	30	30	100	200	360
Metering Pump gal/hr	.0054	.028	.055	.28	.55	2.7	5.5

insulation. These larger storage tanks which have mixers include a steel frame tank stand which attaches to a mixer mount to support the mixer. The larger two systems with storage tanks of 4,540 and 9,460 L (1,200 and 2,500 gal) also include small wooden stairways of 0.9 and 1.8 m high (3 and 6 ft) high, respectively, to enable operators to reach the top of the storage tanks which are 2.1 and 3.2 m high (7 and 10.5 ft) high, respectively. The two largest polyethylene tanks 4,540 and 9,460 L (1,200 and 2,500 gal) also both have a steel banded wooden girdle around the tank which provides additional support and a factor of safety due to the high specific gravity of 1.53 kg/L at 16°C

TABLE 133. CONSTRUCTION COST SUMMARY FOR SODIUM HYDROXIDE FEED SYSTEMS

	Maximum Feed Rate, lb/day of NaOH						
Cost Category	0.8	4	8	42	83	417	834
Storage and Feed Tanks	$ 60	$ 60	$ 90	$ 970	$2,040	$3,560	$ 6,940
Heating and Insulation	---	---	---	200	410	950	1,620
Mixer	---	---	---	180	240	620	640
Wooden Stairway	---	---	---	---	---	300	600
Manual Transfer Pump	100	100	100	---	---	---	---
Pipe and Valves	310	310	310	470	470	530	790
Metering Pump	390	390	390	390	410	1,090	1,100
Containment Wall	120	120	150	270	400	600	880
Labor, Installation	280	280	280	420	480	650	860
Electrical	80	80	80	100	100	120	120
Subtotal	1,340	1,340	1,400	3,000	4,550	8,420	13,550
Design Contingencies	200	200	210	450	680	1,260	2,030
Total	$1,540	$1,540	$1,610	$3,450	$5,230	$9,680	$15,580

(12.8 lb/gal at 60°F) and hazardous nature of the caustic soda solution. The pump is an electronic chemical metering pump which operates on a D.C. solenoid and solid state pulsing circuit. Wetted parts of the pumps are constructed of the following materials: fittings are PVC; head is acrylic; valve balls are ceramic; and elastomers are hypalon.

Pipe and valve costs allow for a minimum of 6.1 m (20 ft) lengths of 2.5 cm (1 in) PVC water supply pipe (for rinsing tanks), 3.8 cm (1 1/2 in) polypropylene drain pipe, and 2.5 cm (1 in) PVC sodium hydroxide transfer and feed pipe. Two drain lines are provided for systems with capacities of 19 kg per day (42 lb/day) and larger, one for the storage tank and one for the feed tank.

The concrete containment wall around the storage tank is 0.2 m (8 in) thick cast-in-place concrete and varies between 0.3 to 0.46 m (1.0 to 1.5 ft) tall for the systems with 760 L (200 gal) and larger tanks. For the 208 L (55 gal) drum, the wall is 0.15 m (0.5 ft) tall, and for 18.9 and 49 L (5 and 13 gal) carboys, the wall is 0.60 m (0.2 ft) tall.

Operation and Maintenance Requirements and Costs

Operation labor requirements include labor for transferring sodium hydroxide solution from the storage tank to the feed tank using a manual hand pump for the smallest systems and by opening and closing a valve in the transfer line for the larger systems. Other labor functions include ordering and receiving deliveries of carboys, drums, and bulk shipments of caustic soda, checking and calibrating the metering pump, checking the operation of the mixer and heating system in the large storage tanks, maintenance and repair of the pump, mixer, and PVC feed lines and valves, and cleaning up infrequent leaks and spills of caustic soda.

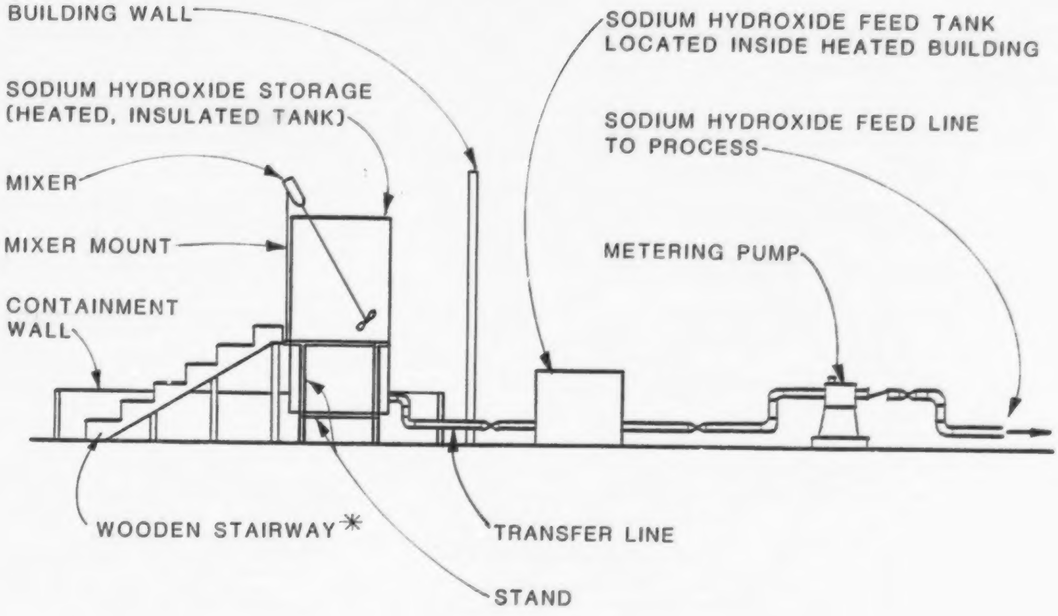
Electrical requirements are for the metering pump which is assumed to operate 24 hours per day, and for the heating and mixing system required for the storage tanks located outdoors. The heating system is assumed to operate 8 hours per day for 90 days per year, and the mixer is assumed to operate 8 hours per day for 150 days per year.

Maintenance material costs are primarily for the metering pump and for the heating and mixing system in the larger tanks (for systems greater than 19 kg/d (42 lb/day)). Some material costs are included for piping and valves which may need occasional repair or replacement. Operation and maintenance requirements are summarized in Table 134 and presented in Figures 126 and 127.

TABLE 134. OPERATION AND MAINTENANCE SUMMARY FOR SODIUM HYDROXIDE FEED SYSTEMS

Average Chemical Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.8	42	50	140	1,600
4	42	50	170	1,900
8	65	50	180	2,000
42	910	100	190	2,300
83	2,040	120	200	2,500
417	4,680	180	240	3,200
834	9,400	240	260	3,800

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.


BUILDING WALL
SODIUM HYDROXIDE FEED TANK LOCATED INSIDE HEATED BUILDING
SODIUM HYDROXIDE STORAGE (HEATED, INSULATED TANK)
SODIUM HYDROXIDE FEED LINE TO PROCESS
MIXER
MIXER MOUNT
METERING PUMP
CONTAINMENT WALL
WOODEN STAIRWAY*
TRANSFER LINE
STAND

*REQUIRED ONLY FOR TWO LARGEST TANKS

Figure 124. **Typical sodium hydroxide feed system installation**

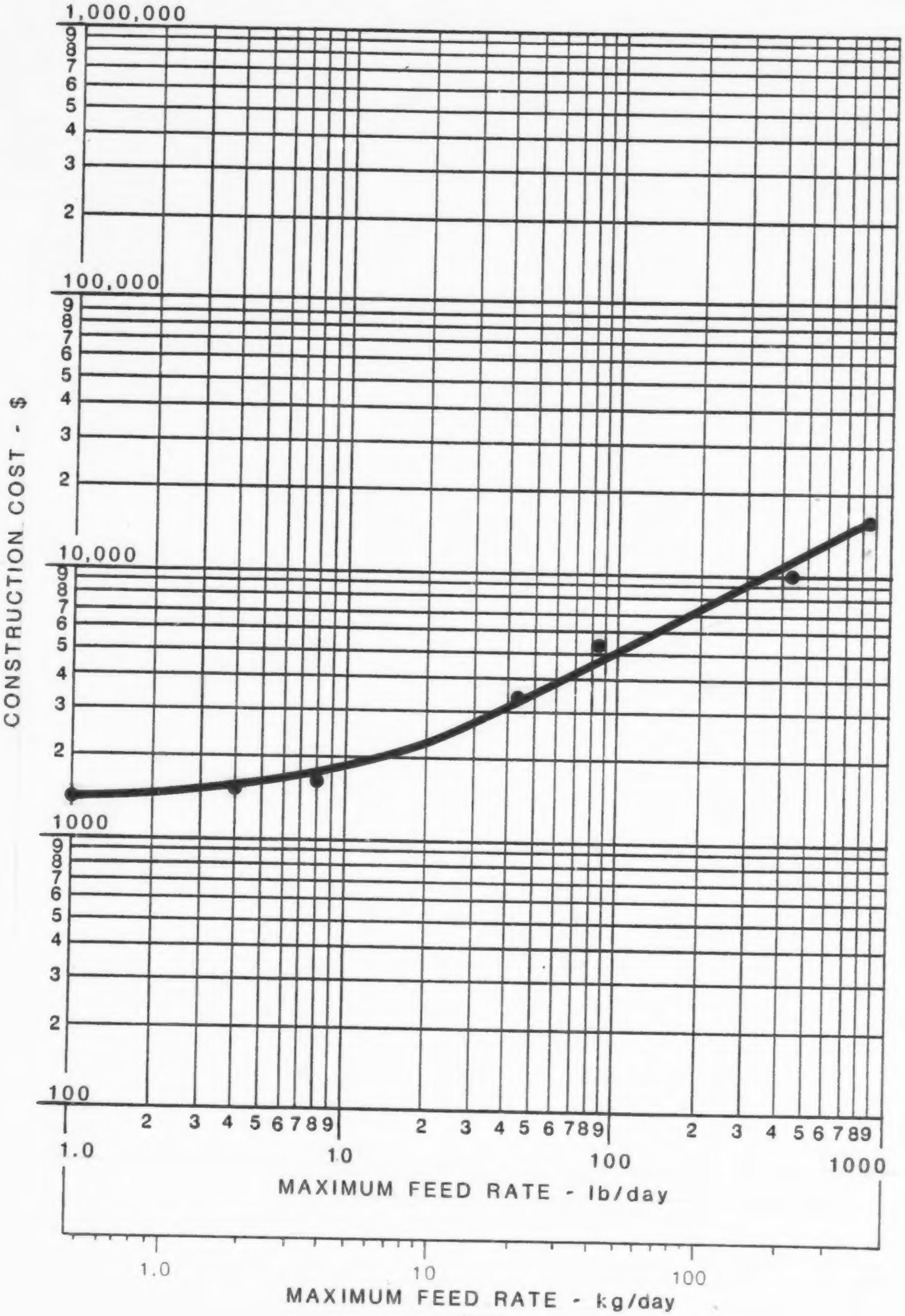


Figure 125. **Construction cost for sodium hydroxide feed systems.**

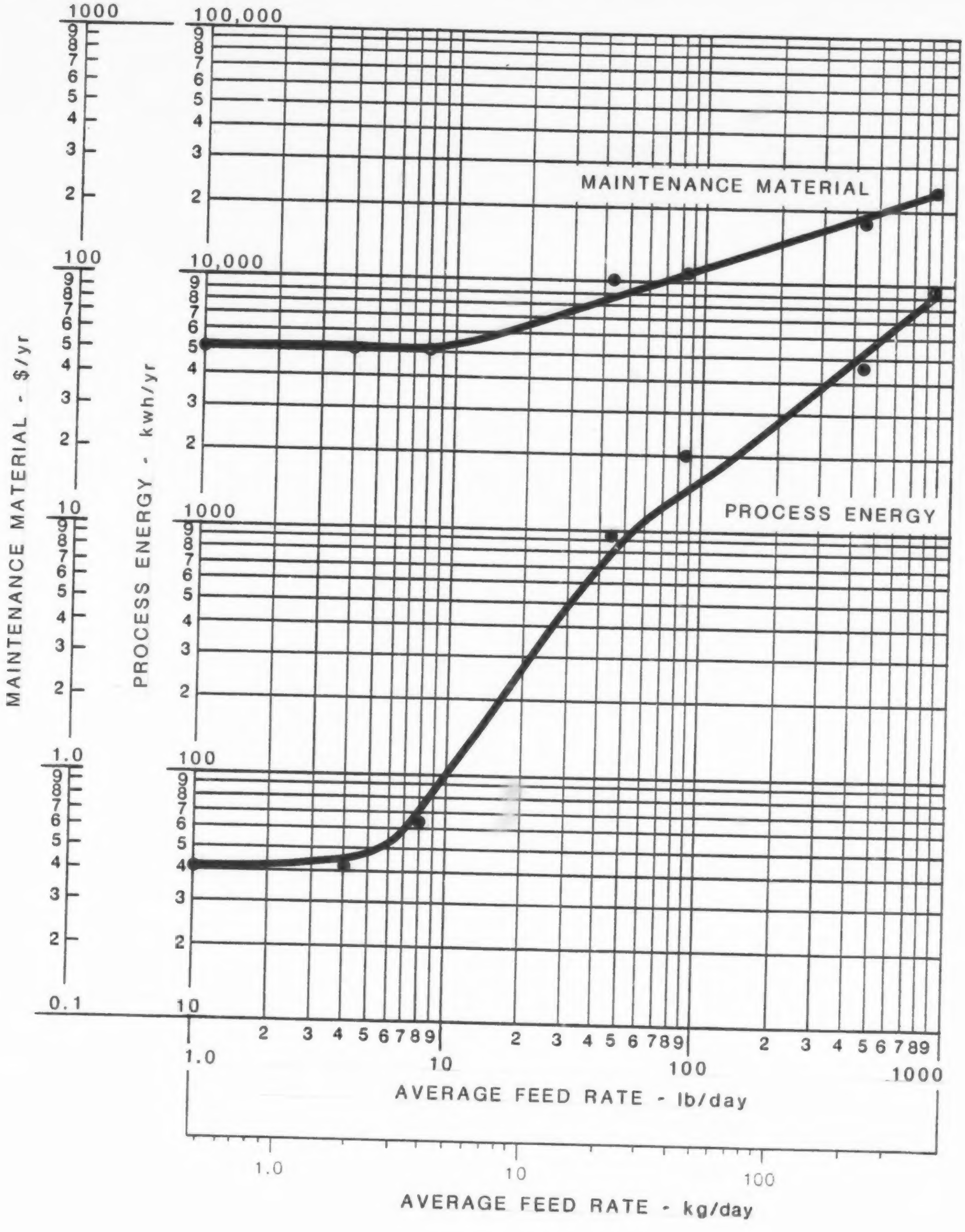


Figure 126. **Operation and maintenance requirements for sodium hydroxide feed systems - process energy and maintenance material.**

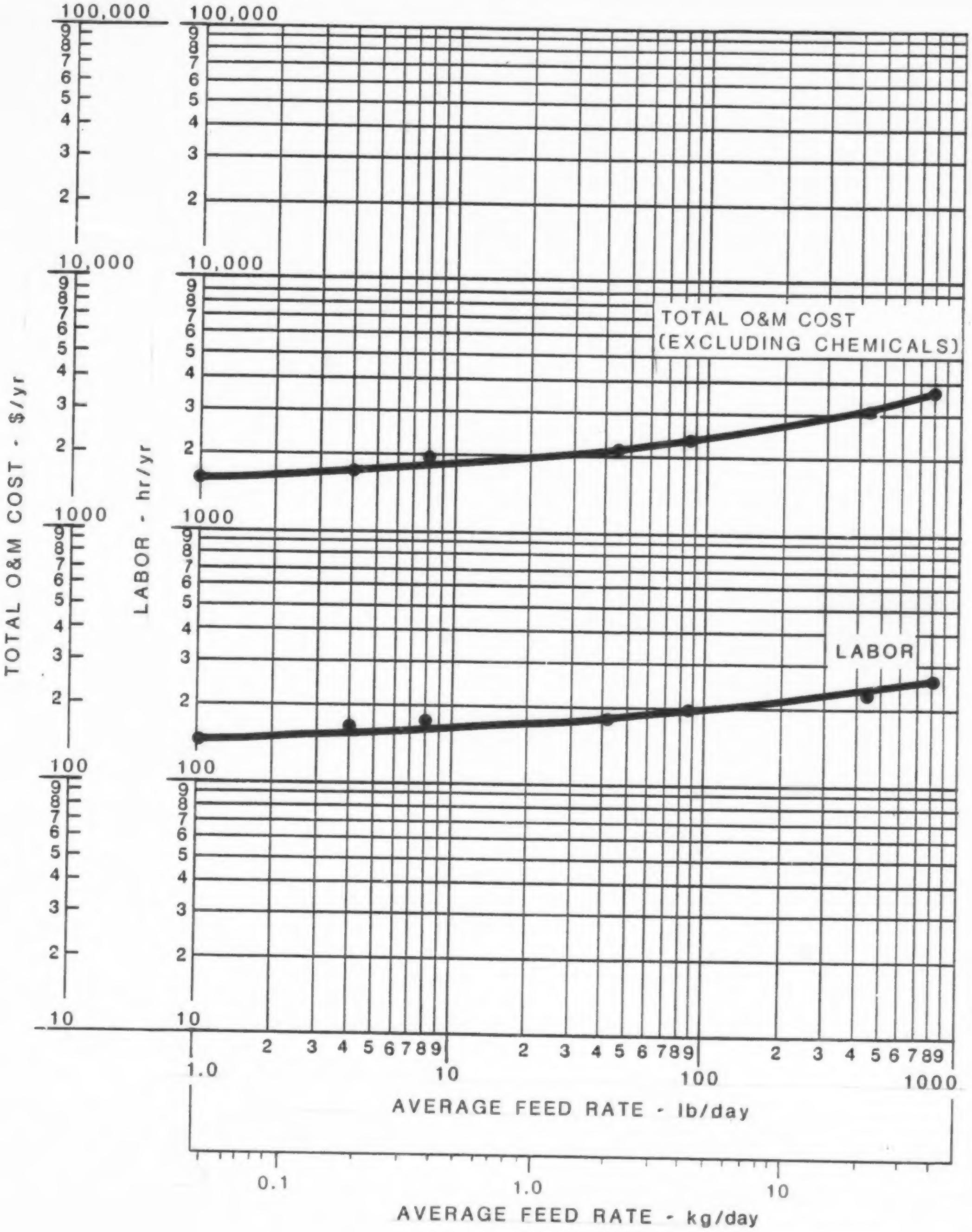


Figure 127. **Operation and maintenance requirements for sodium hydroxide feed systems - labor and total O&M cost.**

POTASSIUM PERMANGANATE FEED SYSTEMS

Introduction

Potassium permanganate, represented by the chemical formula $KMnO_4$, is a strong oxidizing agent. It is used in water treatment plants to oxidize a number of different contaminants: taste and odor compounds; reduced iron and manganese compounds; trihalomethane precursors; and hydrogen sulfide. Potassium permanganate is a solid chemical with a crystalline structure and a bulk density of 1,440-1,600 kg/m^3 (90-100 lb/cu ft). The solubility of potassium permanganate is 4.4 percent by weight at 10°C (50°F), 6.5 percent at 20°C (68°F), and 9.0 percent at 30°C (86°F).

When feeding potassium permanganate solutions in water treatment plants with capacities less than 3,785 m^3/d (1 mgd), a feed system similar to the Basic Chemical Feed System (consisting of a dissolving tank, mixer, and metering pump) is most common. However, the Basic Chemical Feed System is based upon feeding a solution strength of 6 percent, and the solubility of potassium permanganate is about 3 percent, or 0.030 kg/L (0.25 lb/gal). Thus, the cost data for potassium permanganate are based upon mixing and feeding a larger volume of solution per pound of chemical feed, and the potassium permanganate feed costs are higher than for the Basic Chemical Feed System.

Potassium permanganate can also be fed as a dry chemical. Costs presented elsewhere for the Dry Chemical Feeder System are directly applicable, since the construction costs are based upon volume of dry chemical fed per day rather than pounds per day.

Construction Costs

For solution feed of potassium permanganate, conceptual design information for mixing tank volumes, mixer horsepowers, and metering pump capacities is presented in Table 135. For a typical system layout see the Basic Chemical Feed System. Two basic assumptions made in sizing the storage tank were that it should only be necessary to add permanganate once per day (assuming up to 24 hours per day of operation) and that the permanganate should be added to produce a 3 percent solution concentration. The mixing tanks range in size from 114 to 3,785 L (30 to 1,000 gal).

TABLE 135. CONCEPTUAL DESIGNS FOR POTASSIUM PERMANGANATE FEED SYSTEMS

	Maximum Feed Rate, lb/day of $KMnO_4$					
	0.05 to 5	12.5	25	50	125	250
Dissolving Tank						
gal	30	50	100	200	500	1,000
Mixer, hp	1/4	1/3	1/3	1/2	3/4	1.0
Pump Capacity						
gal/day	24	60	120	---	---	---
gal/hr	---	---	---	11	22	42
motor, hp	1/20	1/8	1/8	1/4	1/4	1/4

Construction costs for the potassium permanganate feed systems are summarized in Table 136 and Figure 128. The cost for dissolving tanks is based on using polyethylene tanks, steel frame tank stands, and attached to the stand, a mixer mount which supports the mixer. The pumps are diaphragm type, single head metering pumps. Pipe and valve costs allow for 6.1 m (20 ft) lengths of 2.5 cm (1 in) PVC water supply, 3.8 cm (1 1/2 in) polypropylene drain pipe, and 1.3 cm (1/2 in) PVC chemical solution pipe. It was assumed that both a plant water supply line and a plant sewer line would be located nearby, and that the chemical feed line would apply chemicals to an adjacent rapid mix basin.

TABLE 136. CONSTRUCTION COST SUMMARY FOR POTASSIUM PERMANGANATE FEED SYSTEMS

	Maximum Feed Rate, lb/day of $KMnO_4$					
Cost Category	0.05 to 5	12.5	25	50	125	250
Dissolving Tank	$ 290	$ 430	$ 640	$ 910	$1,830	$2,200
Mixer	180	200	200	240	410	620
Metering Pump	430	700	750	1,230	1,600	1,670
Pipe and Valves	180	180	220	220	280	280
Labor, Installation	180	180	240	260	300	330
Electrical	80	100	150	200	250	300
Subtotal	1,340	1,790	2,200	3,060	4,670	5,400
Design Contingencies	200	270	330	460	700	810
Total	$1,540	$2,060	$2,530	$3,520	$5,370	$6,210

Operation and Maintenance Requirements and Costs

Operation labor requirements for the potassium permanganate feed system include labor for emptying bags of dry chemicals into the dissolving tank, for turning on and off the dissolving tank mixer, for calibrating the chemical metering pump, and for occasional preventative maintenance of the mixer and metering pump.

Electrical requirements are for the mixer and the metering pump. Mixer operation ranges from 30 minutes per day for the smallest system up to 45 minutes per day for the largest system. It is assumed that the chemical metering pump operates continuously, 24 hours per day.

Maintenance material costs are primarily for repair components associated with the mixer and metering pump. Operation and maintenance requirements are summarized in Table 137 and presented in Figures 129 and 130.

TABLE 137. OPERATION AND MAINTENANCE SUMMARY FOR POTASSIUM PERMANGANATE FEED SYSTEMS

Average $KMnO_4$ Feed Rate, lb/day	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
0.05 to 5	120	30	200	2,200
12.5	250	40	270	3,000
25	250	50	290	3,300
50	480	70	300	3,400
125	560	100	320	3,700
250	660	120	430	4,900

Note: Total cost is based on $0.07/kwh of electrical energy and $11/hour of labor.

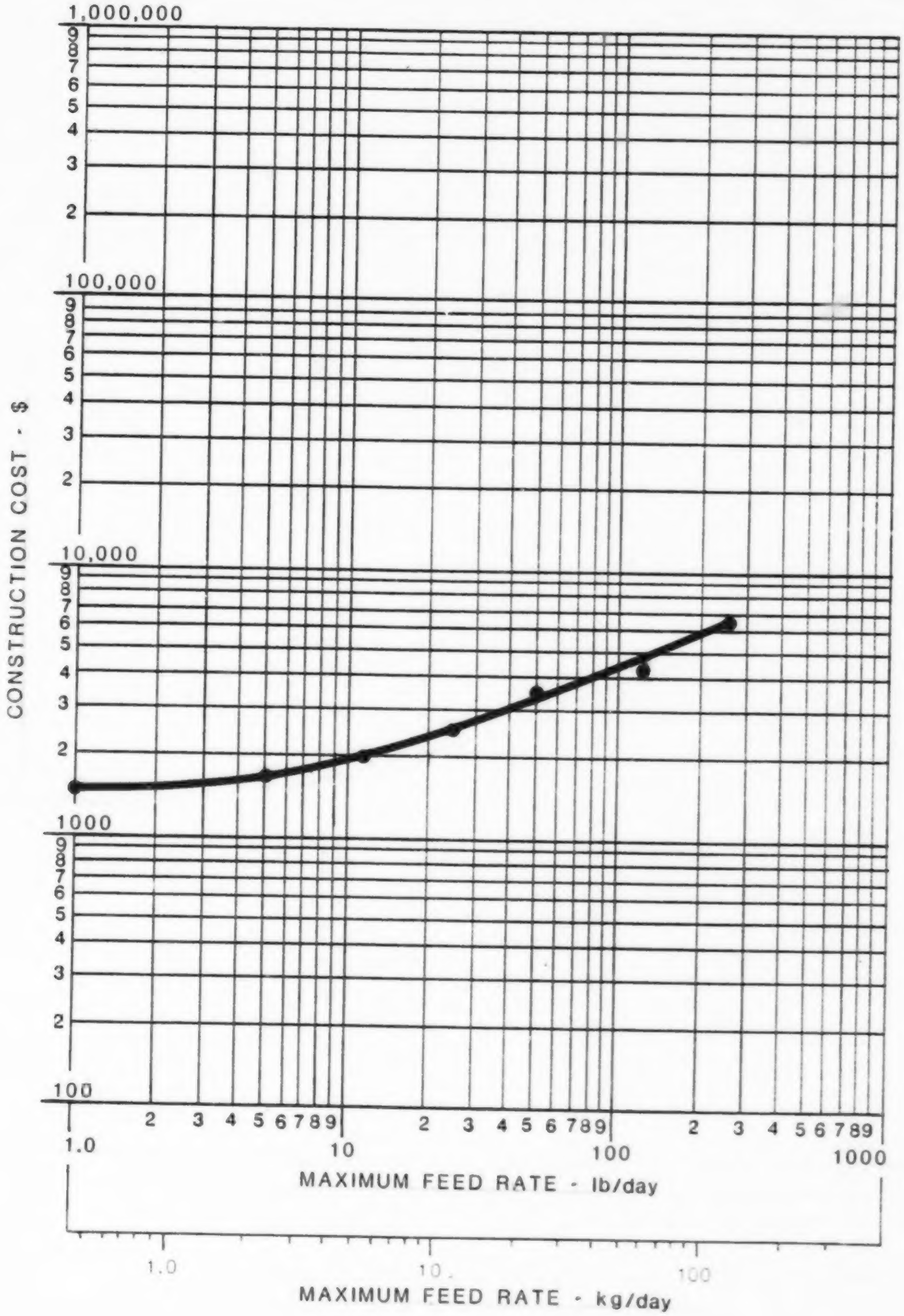


Figure 128. Construction cost for potassium permanganate feed systems.

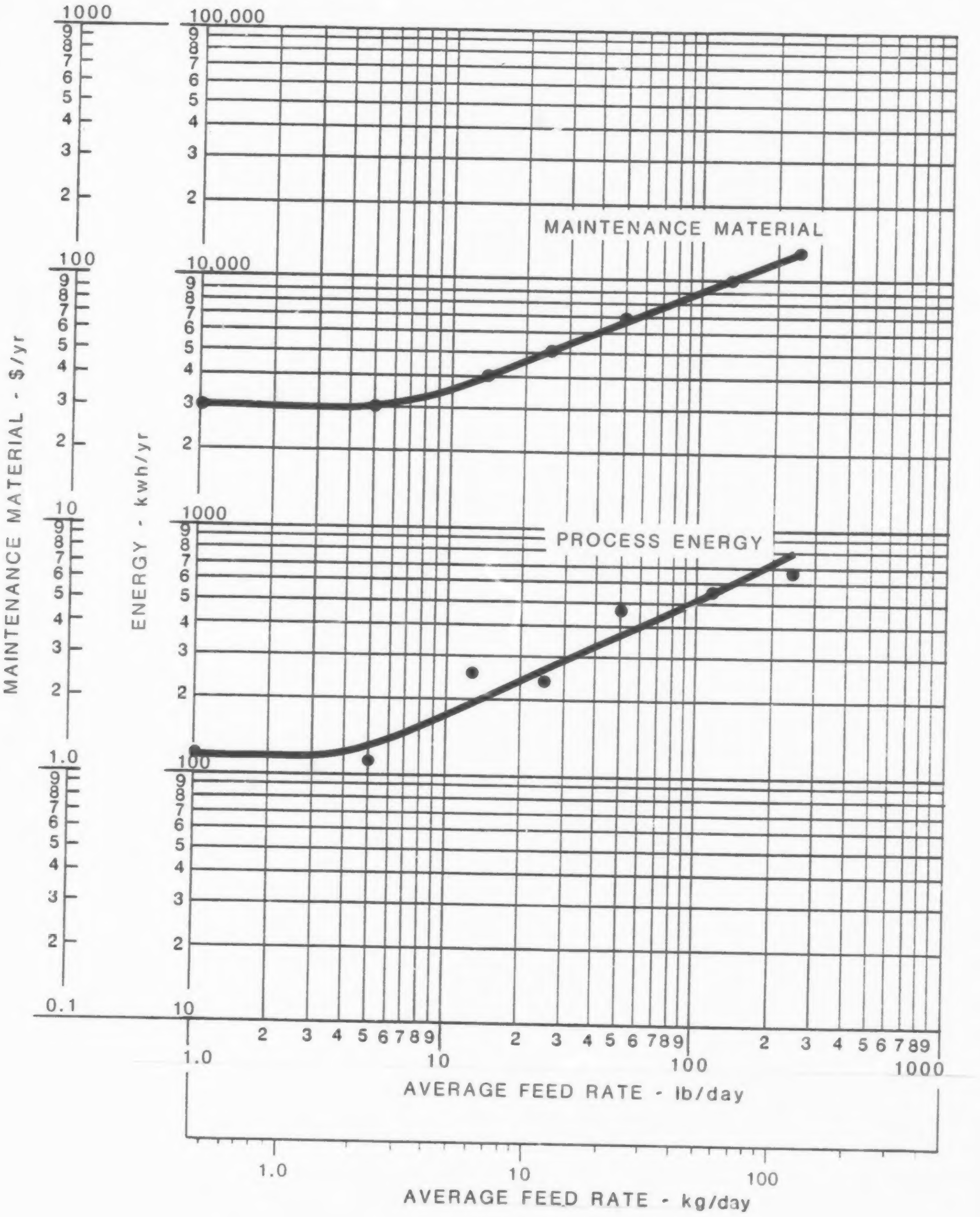


Figure 129. **Operation and maintenance requirements for potassium permanganate feed systems - process energy and maintenance material.**

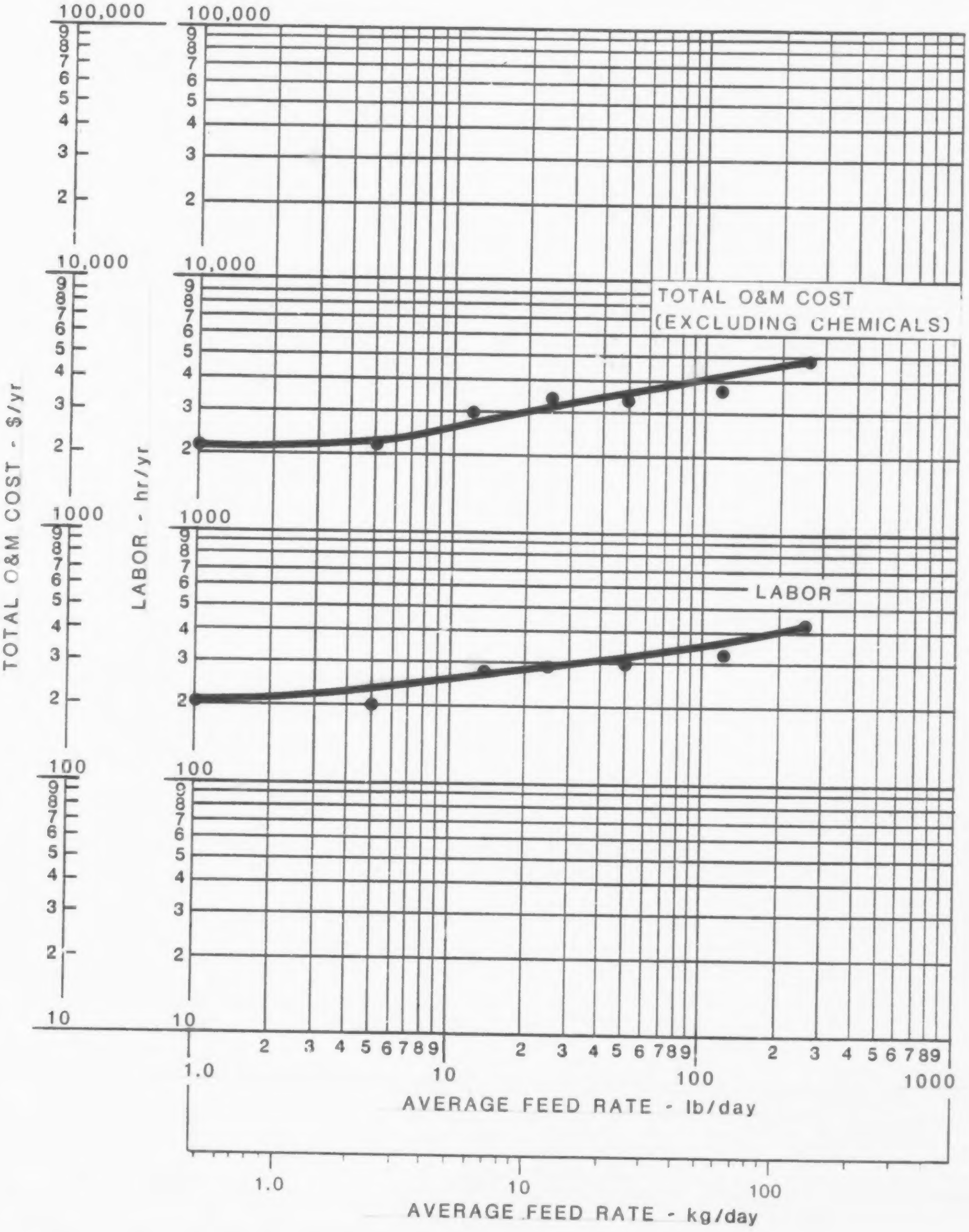


Figure 130. Operation and maintenance requirements for potassium permanganate feed systems - labor and total O&M cost.

FERRIC CHLORIDE FEED SYSTEMS

Introduction

Ferric chloride is occasionally used in water treatment as a coagulant. Ferric chloride is most commonly available as a liquid containing about 40 percent $FeCl_3$. The liquid solution is very corrosive and must be handled with corrosion resistant materials such as PVC, polyethylene, polypropylene, or hypalon. Ferric chloride is a dark brown syrupy liquid which will leave stains or deposits on most materials which it contacts.

Construction Costs

Conceptual designs for ferric chloride feed systems are presented in Table 138, and a typical system layout is shown in Figure 131. The system includes a storage tank which ranges in size from a 19 L (5 gal) carboy to a 4,540 L (1,200 gal) tank. The storage tank is sized to hold a minimum of eight days of storage. A metering pump is used to transfer ferric chloride from the storage tank to the process.

TABLE 138. CONCEPTUAL DESIGNS FOR FERRIC CHLORIDE FEED SYSTEMS

	Maximum Feed Rate, lb/day of $FeCl_3$						
	1	10	25	50	100	250	750
Carboy or Drum gal	5	55	55	--	--	--	--
Storage Tank gal	--	--	--	100	200	500	1,200
Metering Pump gal/hr	.0083	.083	.21	.42	.84	2.1	6.3

Construction costs are for ferric chloride feed systems with feed capacities ranging from 0.45 to 340 kg/d of $FeCl_3$ (1 to 750 lb/day). Construction costs are summarized in Table 139 and presented in Figure 132. The costs for ferric chloride storage tanks are based on using covered polyethylene tanks. The larger two systems with storage tanks of 2,270 and 4,540 L (600 and 1,200 gal) also include small wooden stairways, 0.91 m (3 ft) high, to enable operators to reach the top of the storage tanks, which are 2.1 m (7 ft) high. The largest polyethylene tank has a steel banded wooden girdle around the tank which provides additional support necessary due to the high specific gravity of ferric chloride, 1.40 kg/L (11.7 lb/gal).

The pump is an electronic chemical metering pump which operates on a D.C solenoid and solid state pulsing circuit. Wetted parts of the pump are constructed of the following materials: fittings are PVC; head is acrylic; valve balls are ceramic; and elastomers are hypalon. Pipe and valve costs allow for a minimum of 6.1 m (20 ft) lengths of 2.5 cm (1 in) PVC water supply pipe (for rinsing tank), 3.8 cm (1 1/2 in) polypropylene drain pipe, and 1.3 cm (1/2 in) PVC ferric chloride feed pipe.

TABLE 139. CONSTRUCTION COST SUMMARY FOR FERRIC CHLORIDE FEED SYSTEMS

Cost Category	Maximum Feed Rate, lb/day of $FeCl_3$						
	1	10	25	50	100	250	750
Storage Tank	$---	$---	$---	$---	$ 360	$ 780	$2,040
Wooden Stairway	---	---	---	---	---	300	300
Metering Pump	390	390	390	390	390	1,090	1,100
Pipe and Valves	180	180	180	180	220	280	280
Labor, Installation	120	120	130	130	210	360	410
Electrical	80	80	80	80	100	120	120
Subtotal	770	770	780	780	1,280	2,930	4,250
Design Contingencies	120	120	120	120	190	440	640
Total	$890	$890	$900	$900	$1,470	$3,370	$4,890

Operation and Maintenance Requirements and Costs

Operation labor requirements include labor for ordering and receiving deliveries of carboys, drums, and bulk shipments of ferric chloride. Other labor functions include checking and calibrating the metering pump, maintenance and repair of the pump, checking the feed pipe and valves for leaks, and cleaning up infrequent leaks and spills of ferric chloride.

Electrical requirements are for the metering pump which is assumed to operate continuously, 24 hours per day. Maintenance material costs are primarily for the metering pump. Some material costs are included for piping and valves which may need occasional repair or replacement. Operation and maintenance requirements are summarized in Table 140 and presented in Figures 133 and 134.

TABLE 140. OPERATION AND MAINTENANCE SUMMARY FOR FERRIC CHLORIDE FEED SYSTEMS

Average $FeCl_3$ Feed Rate, lb/day	Process Energy, kwh/hr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
1	42	30	110	1,200
10	99	30	150	1,700
25	125	30	155	1,700
50	135	30	175	2,000
100	140	40	180	2,000
250	325	80	195	2,300
750	590	110	225	2,600

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

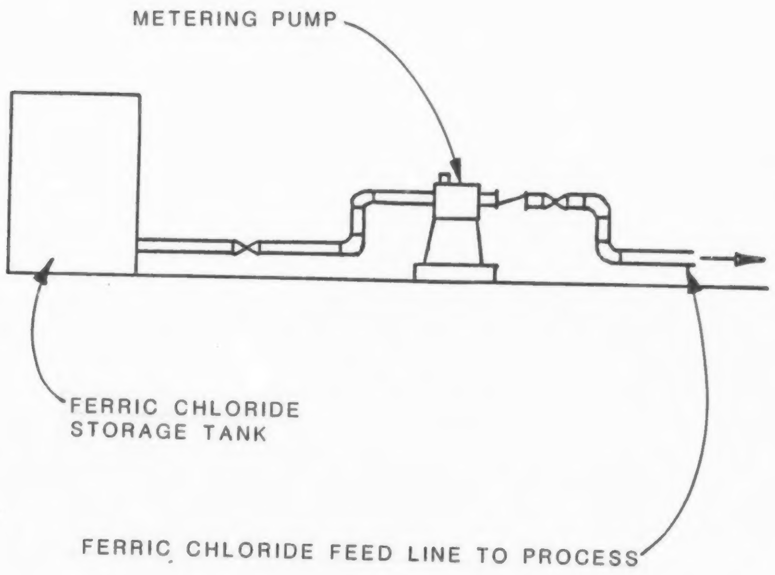

METERING PUMP
FERRIC CHLORIDE STORAGE TANK
FERRIC CHLORIDE FEED LINE TO PROCESS

Figure 131. **Typical ferric chloride feed system installation**

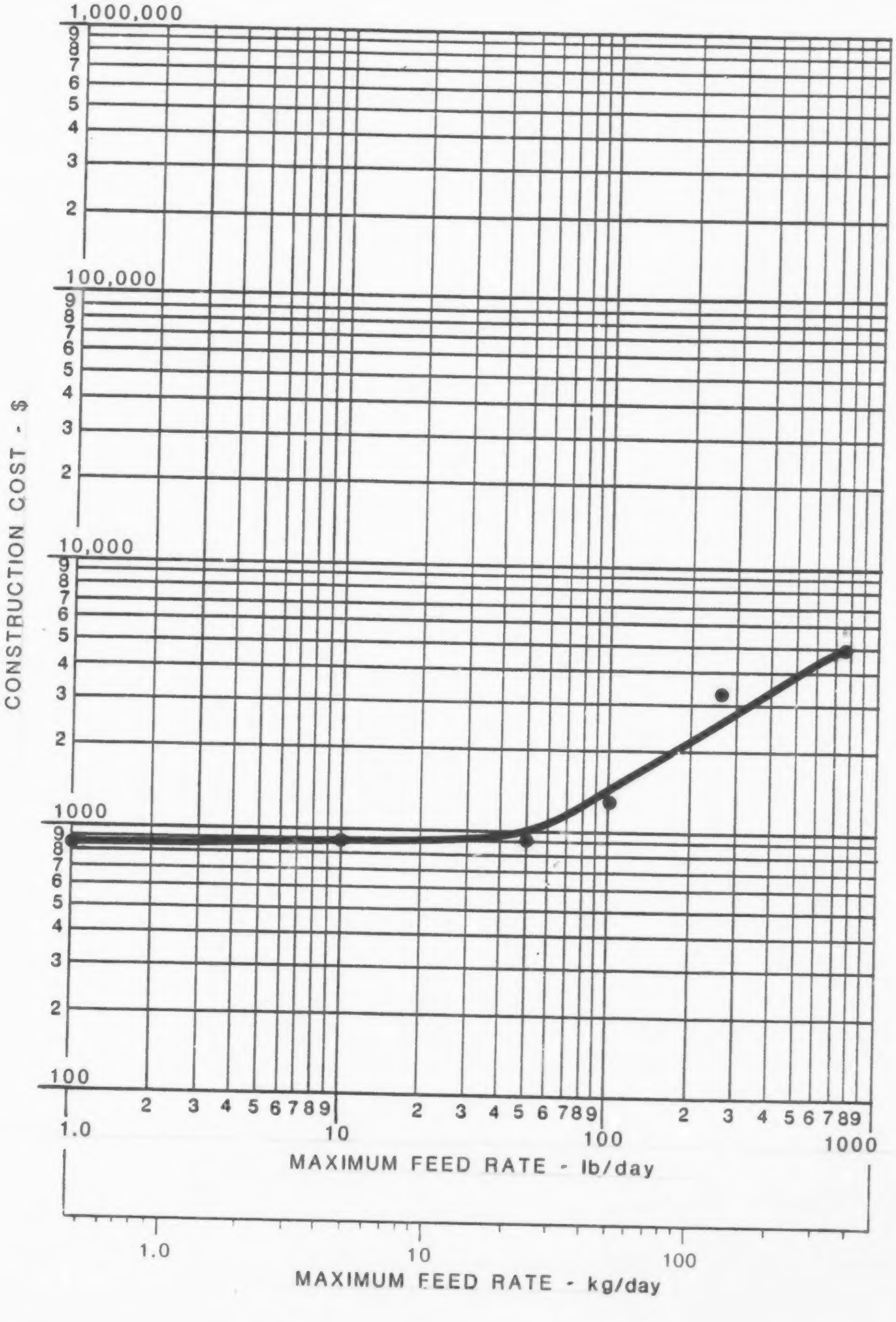


Figure 132. Construction cost for ferric chloride feed systems.

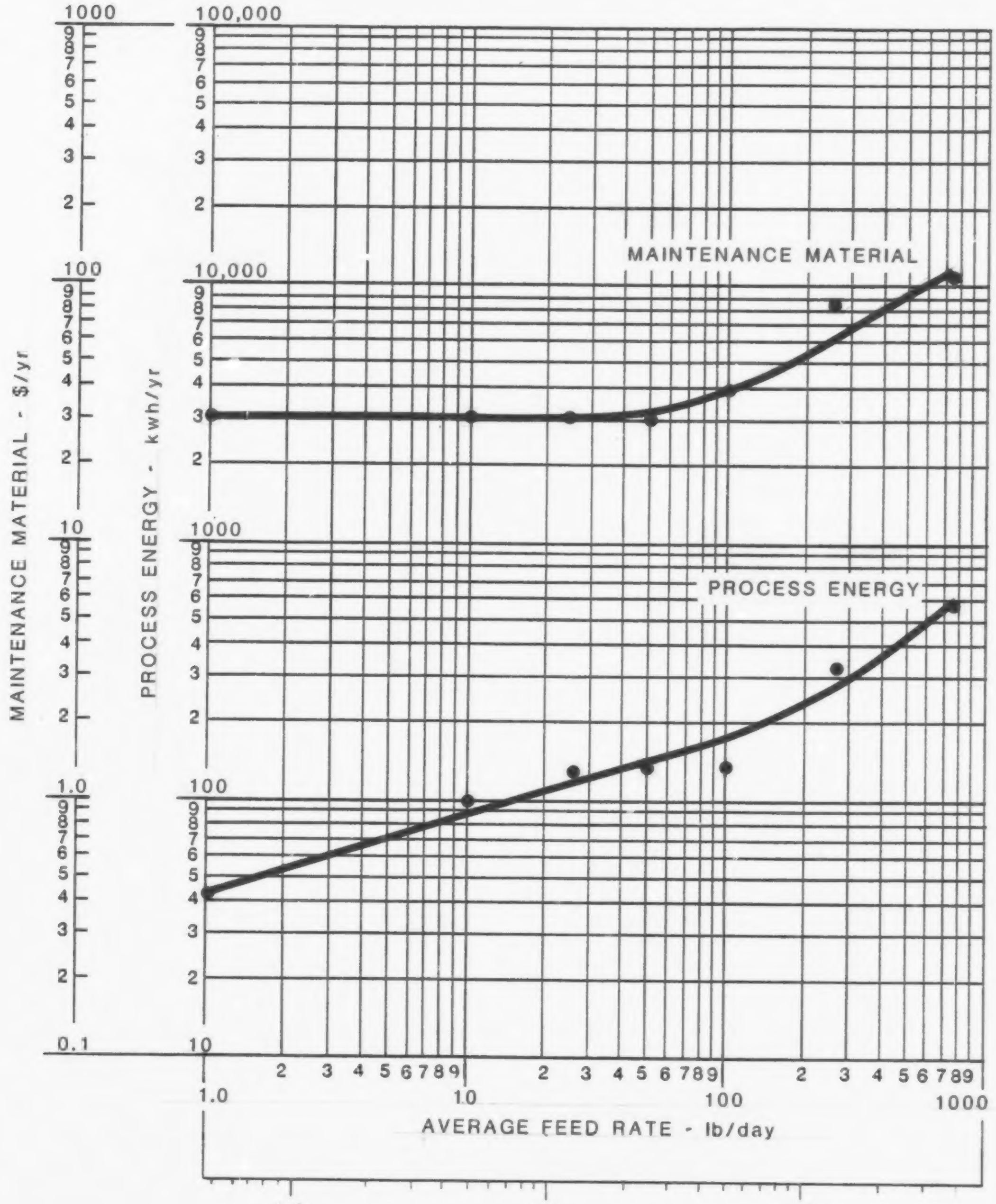


Figure 133. **Operation and maintenance requirements for ferric chloride feed systems - process energy and maintenance material.**

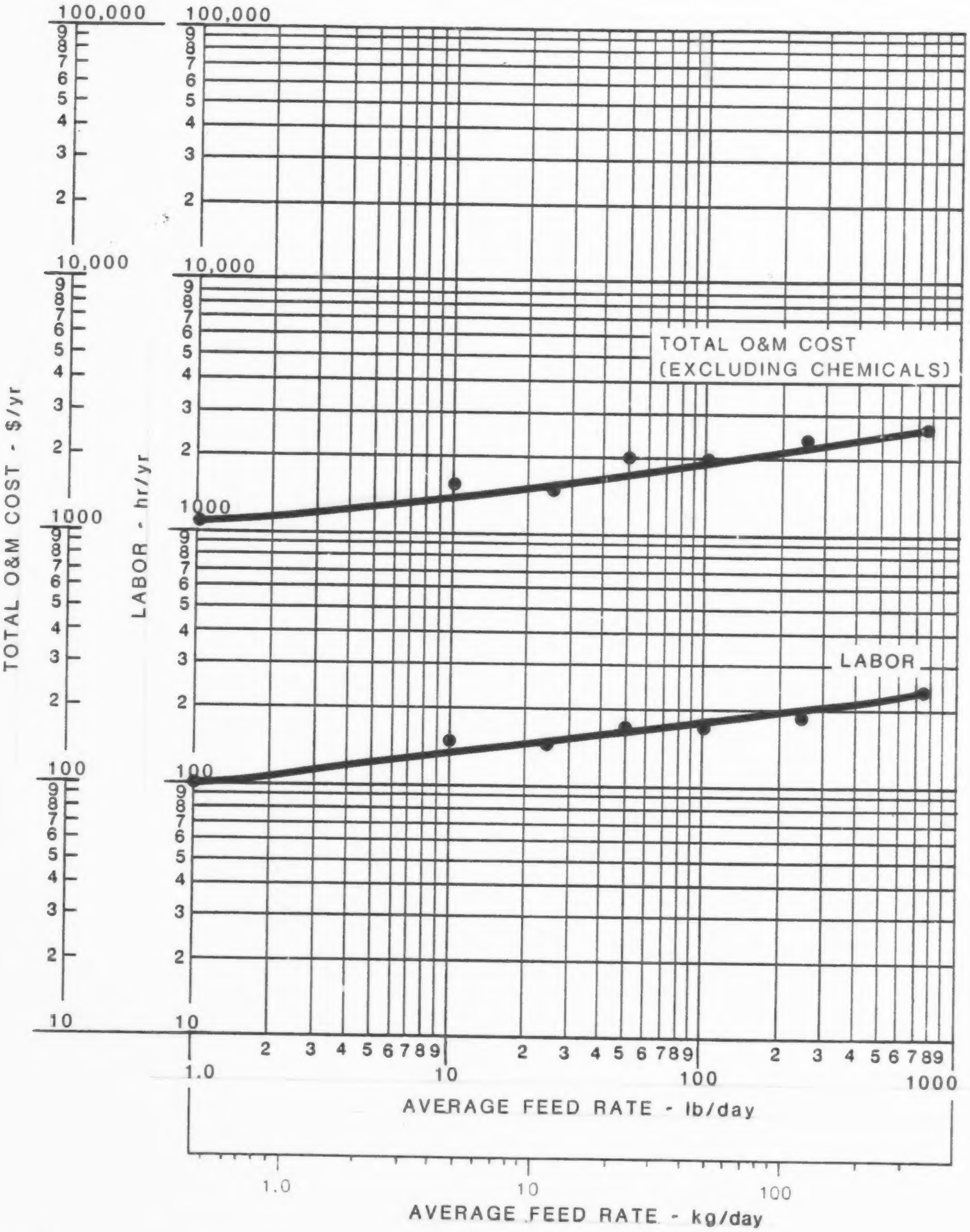


Figure 134. **Operation and maintenance requirements for ferric chloride feed systems - labor and total O&M cost.**

WATER TREATMENT PLANT SLUDGE/BRINE DISPOSAL

A variety of sludges, or in certain cases brine, can be produced during water treatment operations. The principal types of wastes that can be produced are:

- Alum Sludge
- Lime Softening Sludge
- Diatomite Filter Sludge
- Filter Backwash Water
- Brine Wastes

The principal disposal techniques for each type of waste are shown following:

	Sludge Lagoon	Sanitary Sewer	Sand Beds	Return to Plant Headworks	Evaporation Pond
Alum Sludge	X	X	X		
Lime Sludge	X	X	X		
Diatomite Filter Sludge	X	X	X		
Filter Backwash Water	X			X	
Brine		X			X

It is likely also that a number of small plants discharge wastes back to the watercourse which is the original source of the water supply. Such disposal may be allowed on a case-by-case basis by the state agency responsible for granting and enforcing NPDES (National Pollutant Discharge Elimination System) permits.

On the following pages are descriptive write-ups and cost data for sludge handling using sludge dewatering lagoons, discharge to a sanitary sewer, sand drying beds, and evaporation ponds. Mechanical dewatering processes are generally not applicable to plants less than 3,785 m^3/d (1 mgd), and are not included in this report.

SLUDGE DEWATERING LAGOONS

Introduction

Sludge dewatering lagoons are one of the most commonly used techniques to thicken or dewater water treatment sludges. Lagoons are most applicable to lime sludges, although they can be used for alum sludges in certain situations. Lime sludge will dewater to between 20 and 40 percent solids when a supernatant layer is present, and up to 50 percent solids if the supernatant is decanted and the sludge is allowed to air dry. After air drying, sludge is typically removed using a front-end loader and hauled to disposal.

Conversely, alum sludge consolidates poorly in lagoons, particularly when it is submerged under a supernatant layer. When supernatant is decanted, alum sludge concentrations of 10-15 percent can be reached, with a hard crust forming on the surface. Removal is difficult, as the sludge turns to a viscous liquid with essentially no shear resistance when agitated. Often, alum sludge is allowed to further air dry after removal from the lagoon, and prior to hauling from the plant site.

Lagoons are frequently designed to provide several years of storage and consolidation prior to removal of solids. At other plants, lagoons are constructed and operated as a permanent depository for sludge solids, with a new lagoon(s) being constructed when the old lagoon is filled with solids to the point that it is no longer usable.

Construction Costs

Construction costs were developed for earthen lagoons constructed from material excavated on-site. Earthwork costs are based upon sandy loam material, with the volume of excavated material equal to the volume of the lagoon berm. Side slopes of 2:1 were used for the lagoons, which have a usable depth of 1.52 m (5 ft) plus a 0.61 m (2 ft) freeboard. The lagoons are not lined, and downward percolation of water is beneficial during the drying stage of the dewatering process.

Lagoons are generally constructed using two or more basins, although small plants may only use one lagoon. Conceptual design information used in the development of dewatering lagoon costs is presented in Table 141. When more than one basin is used, a 3.66 m (12 ft) wide road is included between basins. The lagoons include an inlet structure designed to minimize the disturbance of settled sludge, and an outlet structure which is used to remove supernatant from the lagoon.

Construction costs are presented in Table 142 and Figure 135 on the basis of effective storage volume of lagoons. This effective volume is the total lagoon volume excluding freeboard. Land cost is not included in the construction cost.

Construction costs do not include a front-end loader to be used for dewatered sludge removal. Instead, the cost for the loader is included in the O & M costs, on the assumption that the loader would be rented on an hourly basis.

TABLE 141. CONCEPTUAL DESIGNS FOR SLUDGE DEWATERING LAGOONS

Effective Storage Volume, cu ft	Number of Basins	Effective Lagoon Dimensions, ft Lagoons	Width	Depth
2,500	1	30	30	5
8,500	1	50	50	5
17,500	2	50	50	5
26,000	2	60	60	5
49,000	2	80	80	5
73,300	2	105	105	5
109,900	3	105	105	5
146,500	4	105	105	5

Note: Effective lagoon dimensions do not include additional dimensions required for freeboard.

Operation and Maintenance Requirements and Costs

Requirements for lagoon operation and maintenance are based upon the quantity of dewatered sludge removed from the lagoons. An additional component which may have to be added in some cases is the cost of grass mowing and/or weed control on the lagoon berms. This requirement will vary between plants, and at many plants will be negligible.

Diesel fuel requirements are for a wheel mounted front-end loader used to remove dewatered sludge from the lagoon. Usually, this approach would only be applicable to lime sludge, as alum sludge, even after air drying, generally can not be removed with a front-end loader. Fuel requirements are based upon the removal of 7.6 m^3/h (10 cu yd/hr) and a fuel consumption of 9.5 L/h (2.5 gal/hr) for the loader. The cost for hauling dewatered sludge from the plant site is not included in these costs; hauling costs are included in the section titled "Dewatered Sludge Hauling."

Maintenance and equipment requirements are for the front-end loader and include an hourly cost for equipment rental and equipment maintenance. This concept was used because the annual hours of equipment usage are not sufficient to justify the purchase of a front-end loader to be used for dewatered sludge removal. A cost of $24.00/hour was used for equipment rental and maintenance.

Labor requirements are for operation of the front-end loader, and the hours per year of labor are equivalent to the hours per year of loader operation plus an allowance for initial startup and cleanup of equipment following sludge removal operations. Sludge removal was assumed to be once per year.

Operation and maintenance requirements and costs are summarized in Table 143 and in Figures 136 and 137.

TABLE 142. CONSTRUCTION COST SUMMARY FOR SLUDGE DEWATERING LAGOONS

Cost Category	Effective Storage Volume, cu ft							
	2,500	8,500	17,500	26,000	49,000	73,300	110,000	147,000
Excavation and Sitework	$ 700	$1,300	$2,300	$3,100	$ 5,600	$ 8,300	$12,200	$16,300
Concrete	200	200	400	400	400	400	600	800
Labor, Installation	700	1,100	2,600	3,200	4,700	6,300	9,400	12,500
Pipe and Valves	200	200	800	900	1,000	1,000	1,600	2,100
Subtotal	1,800	2,800	6,100	7,600	11,700	16,000	23,800	31,700
Design Contingencies	200	400	900	1,100	1,800	2,400	3,600	4,800
Total	$2,000	$3,200	$7,000	$8,700	$13,500	$18,400	$27,400	$36,500

TABLE 143. OPERATION AND MAINTENANCE SUMMARY FOR SLUDGE DEWATERING LAGOONS

Annual Volume of Sludge Removed, cu ft/yr	Diesel Fuel, gal/yr	Equipment and Maintenance, $/yr	Labor, hr/yr	Total Cost, $/yr
500	5	50	6	120
1,000	10	90	8	190
5,000	50	450	23	760
10,000	95	890	41	1,450
20,000	185	1,780	78	2,850

Note: Total cost is based on $1.10/gal of diesel fuel and $11.00/hour of labor.

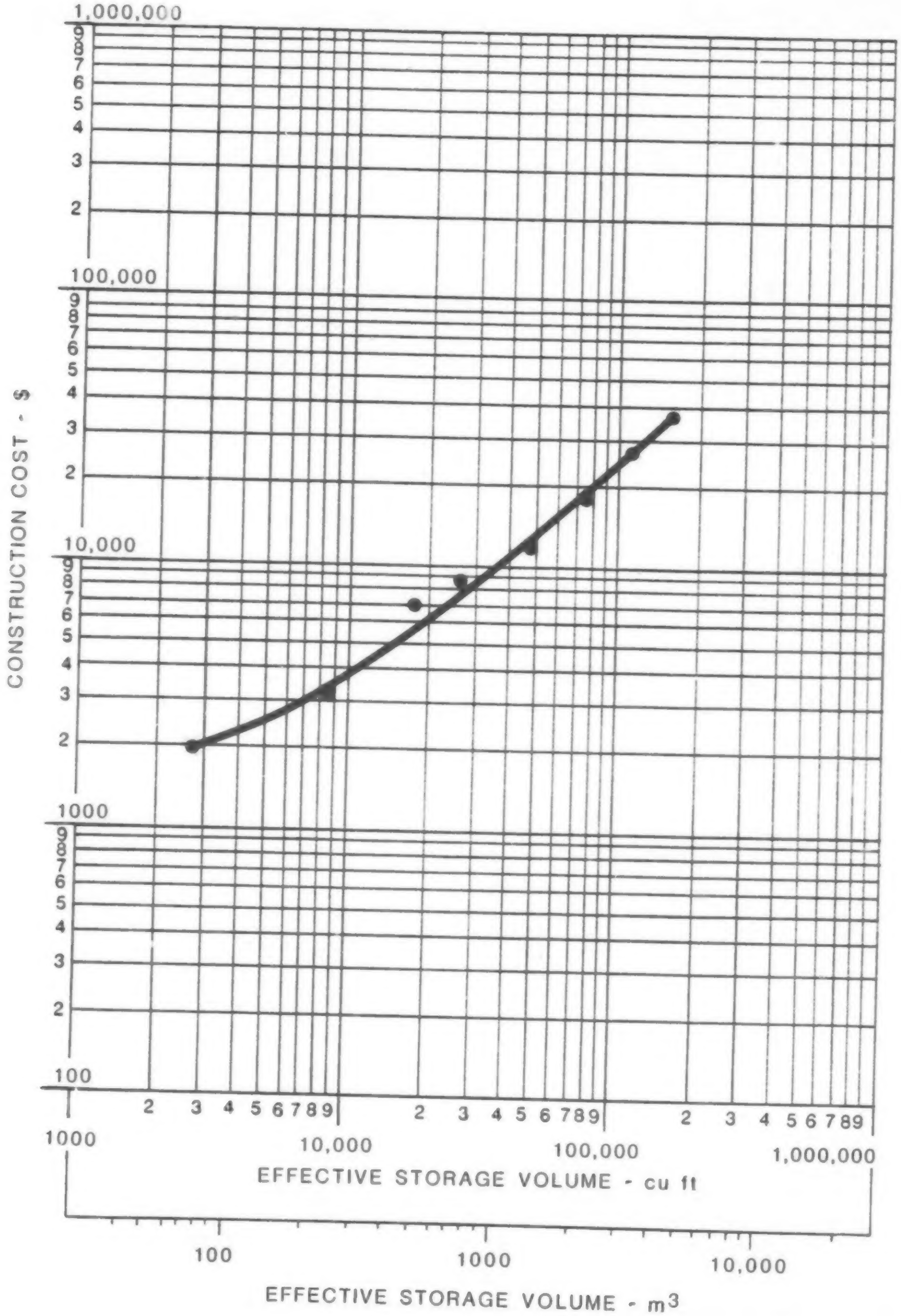


Figure 135. Construction costs for sludge dewatering lagoons.

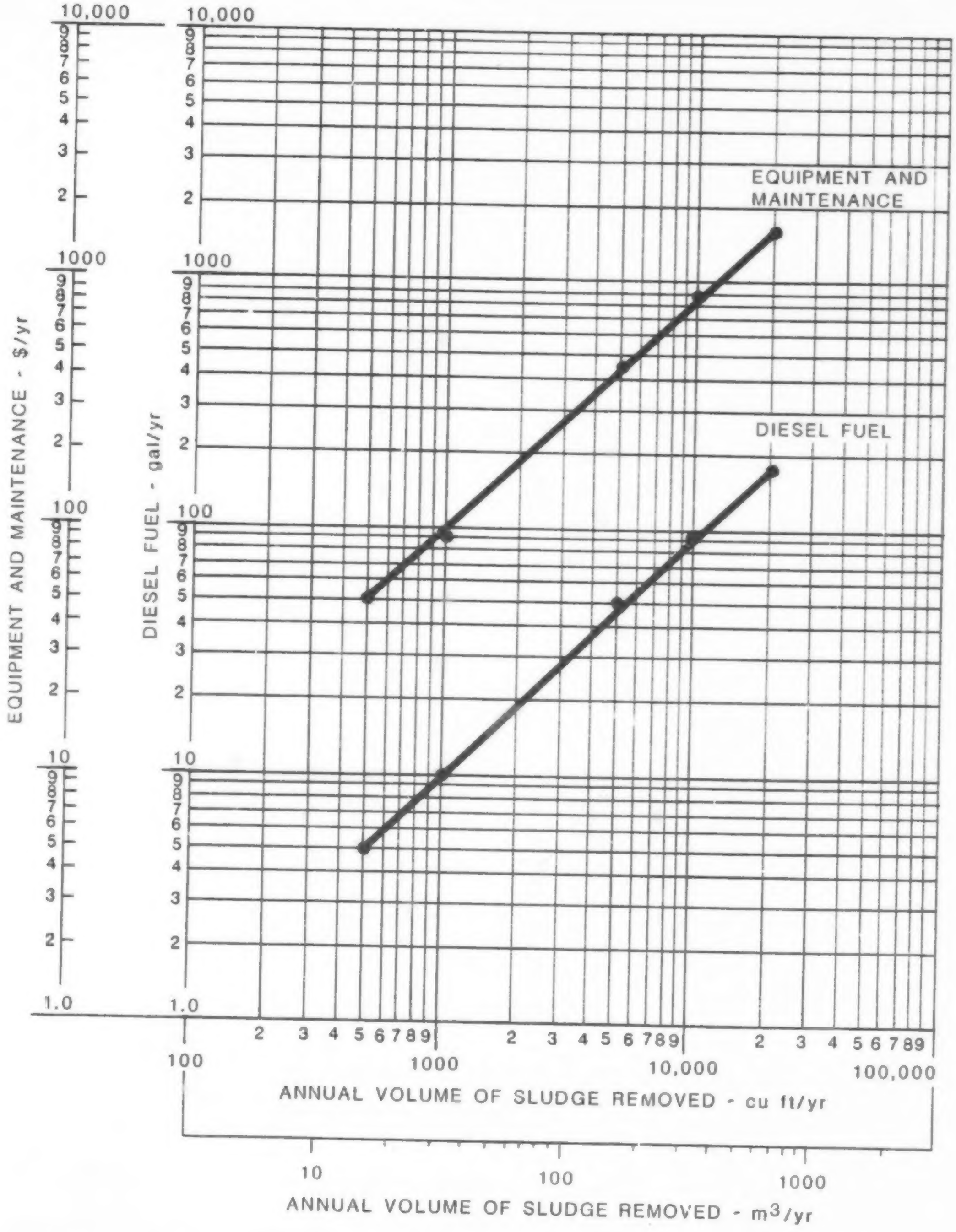


Figure 136. Operation and maintenance requirements for sludge dewatering lagoons - equipment and maintenance and diesel fuel.

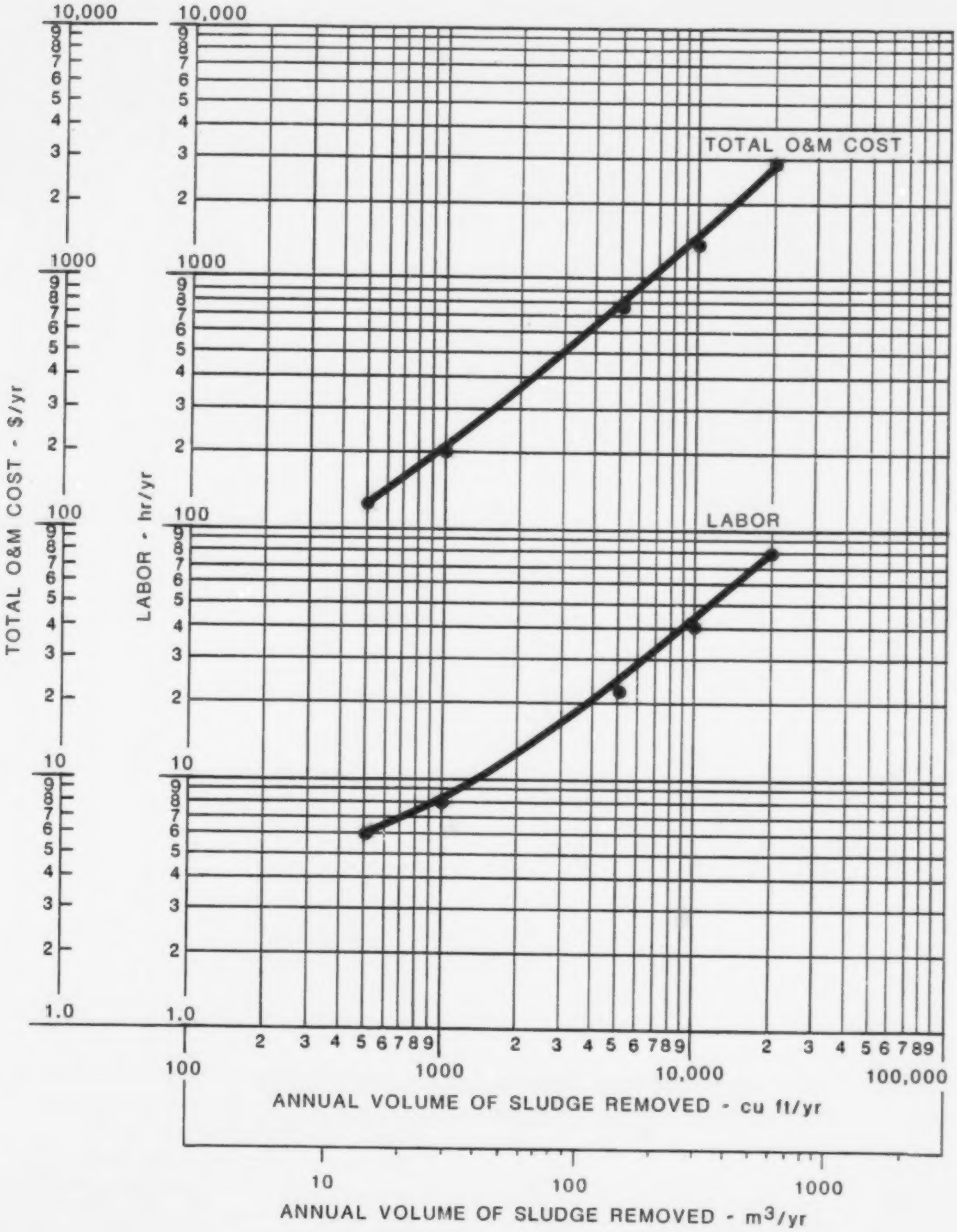


Figure 137. **Operation and maintenance requirements for sludge dewatering lagoons - labor and total O&M cost.**

SLUDGE DISPOSAL TO SANITARY SEWERS

Introduction

Discharge into sanitary sewers is a common method of sludge and filter backwash disposal. A survey of water treatment plants in 1968 found that 8.3 percent disposed of their sludge to sanitary sewers.[1] A subsequent survey of lime-soda softening plants in 1981 found that 8 percent disposed of their sludges to sanitary sewers.[2] Disposing of sludge to sanitary sewers merely moves the place of treatment and final disposal to the wastewater treatment plant, and while the unit cost of treatment and disposal may benefit from economy of scale at the wastewater treatment plant, the costs associated with water treatment plant sludge disposal will still be significant.

There are a number of factors which should be evaluated when considering sludge disposal to the sanitary sewers. A major consideration is the ability of the wastewater treatment plant to accept the increased hydraulic and solids loads. It has been demonstrated that water treatment sludges benefit primary sedimentation and to some extent COD removal in wastewater treatment plants. However, it would be a rare, but fortuitous circumstance when an existing wastewater treatment plant solids handling system could handle the unplanned addition of water treatment plant sludges, when the water treatment and wastewater treatment plants were of comparable size. Another important consideration is the capacity of the receiving sewer. The hydraulic capacity of the sewer must be matched to the discharge flow rate. In addition, minimum velocities must be maintained in the sewer to prevent solids deposition. This is particularly important for the higher solids content sludges from lime softening plants, which can approach 100,000 mg/L.

Impact of Raw Water Quality on Costs

The quality of the raw water impacts sludge disposal costs by determining the volume, concentration, and type of sludges produced. Increasing turbidity will produce increasing amounts of chemical/coagulant sludges and filter backwash waters. High concentrations of iron and manganese will produce filter backwash water containing inorganic precipitates. Increasing hardness will require lime or lime-soda softening and produce increasing amounts of calcium carbonate-magnesium hydroxide sludges.

Annual Costs

The cost for sludge treatment and disposal at a wastewater facility will vary widely from location to location, depending on the concentration of the water treatment plant sludge, the type of sludge treatment and disposal facilities at the wastewater treatment plant and the degree of treatment provided. In accordance with PL 95-217, the Water Quality Act, and associated regulations, most wastewater treatment agencies are implementing or have implemented user charge systems that allocate the cost of treatment to the various characteristics of wastewater e.g., volume, BOD load, and suspended solids load. To estimate the cost of treating sludge from a water treatment plant, the following unit charges were used:

Volume - \$0.179 per m^3 (\$678/million gal)
BOD Load - \$180.6/thousand kg (\$82/thousand lb)
Suspended Solids Load - \$152/thousand kg (\$69/thousand lb)

These unit charges were developed from user charge information from approximately 40 wastewater treatment plants.[3] Table 144 presents the annual cost of discharging water treatment sludges at flow rates between 1.26 and 1262 L/s (20 and 20,000 gpm) and suspended solids concentrations between 1,000 and 100,000 mg/L to the wastewater treatment system. Because the BOD loads of water treatment sludges are usually small in comparison to volume and suspended solids loads, the BOD concentration was assumed to be constant and equal to 50 mg/L. BOD concentrations would have to equal a significant portion of the suspended solids concentration before they would significantly change the estimated costs listed in Table 144 and presented in Figure 138.

References

1. Krasauskas, J.W., "Review of Sludge Disposal Practices," Journal AWWA, Volume 61, May 1969, pp. 225-230.

2. "Lime Softening Sludge Treatment and Disposal," Journal AWWA, Volume 73, November 1981, pp. 600-608.

3. "Sewer Charges for Wastewater Collection and Treatment--A Survey," Water Pollution Control Federation, 1982.

TABLE 144. ANNUAL COST SUMMARY FOR SLUDGE DISPOSAL TO SANITARY SEWERS

Sludge Flow Rate, gpd	Suspended Solids Concentration, mg/L						
	1,000	2,000	5,000	10,000	20,000	50,000	100,000
20	$ 10	$ 15	$ 25	$ 50	$ 90	$ 220	$ 430
50	25	30	70	120	220	540	1,100
100	50	70	130	240	450	1,100	2,100
200	90	140	260	470	900	2,200	4,300
500	240	340	660	1,200	2,200	5,400	10,600
1,000	470	680	1,300	2,400	4,500	10,800	21,300
2,000	940	1,400	2,600	4,700	8,900	21,500	42,500
5,000	2,400	3,400	6,600	11,800	22,300	53,800	106,000
10,000	4,700	6,800	13,100	23,600	44,600	108,000	213,000
20,000	9,400	13,600	26,200	47,200	89,200	215,000	425,000

Note: Annual costs are based on the following unit costs: volume, $678 per million gal; BOD, $82 per thousand lb; and suspended solids, $69 per thousand lb.

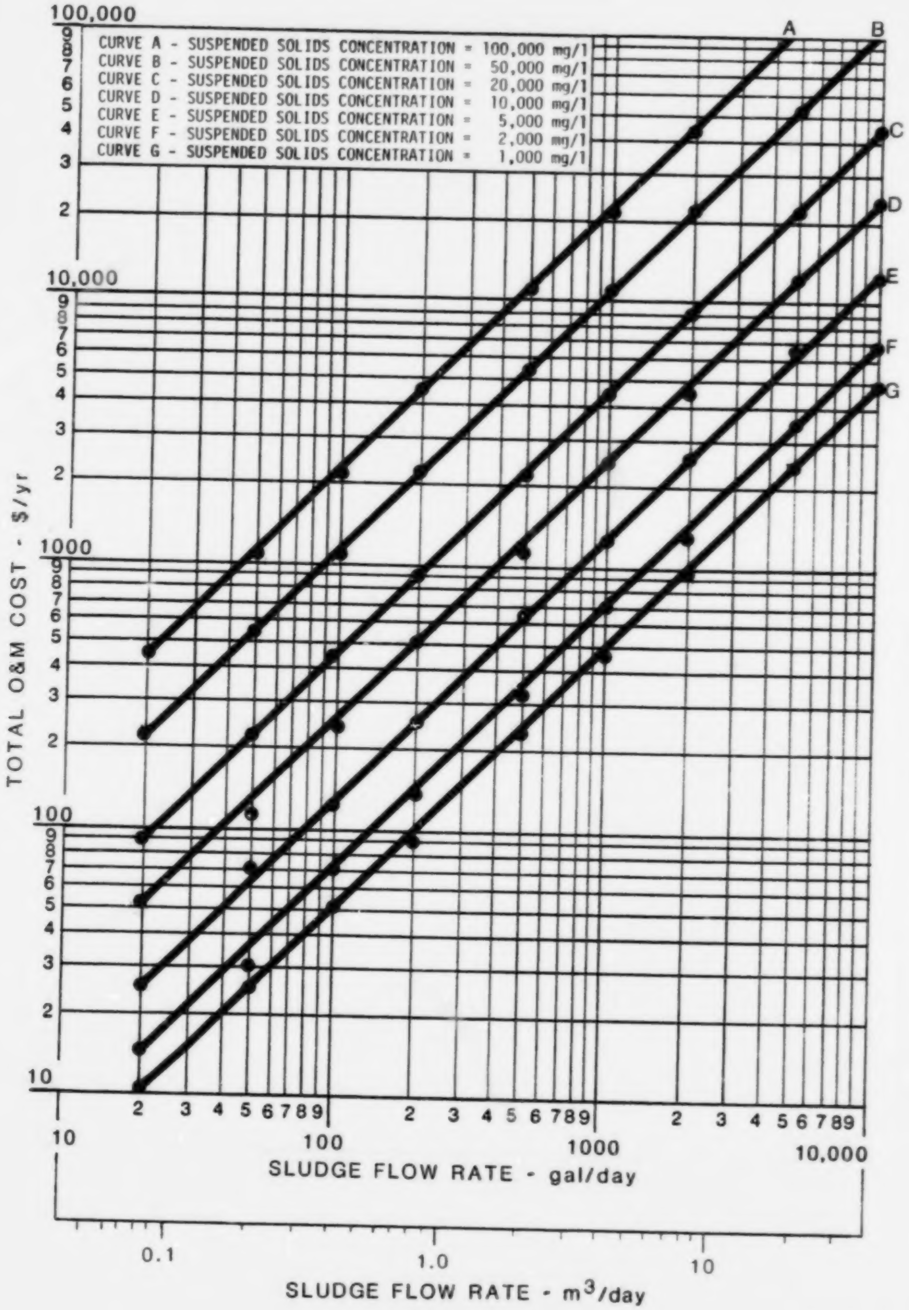


Figure 138. **Total O&M cost for sludge disposal to sanitary sewers.**

SAND DRYING BEDS

Introduction

Following application of liquid sludge to sand drying beds, water removal occurs by both gravity drainage and evaporation. Although, both mechanisms are necessary for adequate dewatering, gravity drainage is the most important.

The rate of gravity drainage is a function of the type of sludge, the depth of applied sludge, and whether the sludge has been conditioned. In general, lime sludges exhibit good drainage, while alum sludges have poor drainability. Alum sludge normally requires conditioning by the addition of polyelectrolytes. Without conditioning, alum sludge frequently penetrates into the sand bed, resulting in poor solids capture and the need for frequent sand replacement. With conditioning, solids capture increases, dewatering time is decreased, and the depth of applied sludge can be increased. The rate of water loss by evaporation is influenced by the exposed surface area of the sludge, the evaporation rate from the sludge surface, and the local precipitation pattern.

Construction Costs

Sand drying beds used at water treatment plants are basically identical to those used at wastewater treatment plants. A typical design would use a 22.9 to 30.5 cm (9 to 12 in) layer of washed and graded sand over a 30.5 cm (12 in) graded gravel layer. Underdrain pipes to remove drainage water are utilized at a maximum spacing of 6.1 m (20 ft). Concrete divider walls with a 0.91 m (3 ft) height are used to separate beds and on the periphery of the beds. Conceptual designs for drying beds are shown in Table 145, and construction costs are presented in Table 146 and Figure 139.

TABLE 145. CONCEPTUAL DESIGNS FOR SAND DRYING BEDS

Total Bed Area, sq ft	Number of Beds	Dimensions of Individual Beds LxW, ft
200	2	10x10
500	2	16x16
800	2	20x20
1,200	3	25x25
1,600	4	20x20
2,000	5	20x20

Operation and Maintenance Requirements and Costs

Energy requirements are for diesel fuel required for the front-end loader which is used to remove dewatered sludge from the sand beds. Diesel fuel requirements are based upon usage at a rate of 5.7 L/h (1.5 gal/hr), with annual hours of usage based on 10.76 h/100 m^2 (1 hr/100 sq ft) for total bed

TABLE 146. CONSTRUCTION COST SUMMARY FOR SAND DRYING BEDS

Cost Category	Total Bed Area, sq ft					
	200	500	800	1,200	1,600	2,000
Excavation and Sitework	$ 200	$ 400	$ 600	$ 900	$ 1,200	$ 1,500
Concrete*	800	1,500	2,200	3,500	4,200	5,200
Steel	100	200	200	300	400	400
Labor, Installation	1,400	2,000	2,400	4,200	4,500	5,600
Pipe and Valves	600	600	700	1,100	1,300	1,600
Subtotal	2,100	4,700	6,100	10,000	11,600	14,300
Design Contingencies	300	700	900	1,500	1,800	2,200
Total	$2,400	$5,400	$7,000	$11,500	$13,400	$16,500

Note: *Includes sand.

areas equal to or less than 74.3 m^2 (800 sq ft) and 8.07 h/100 m^2 (0.75 hr/100 sq ft) for total bed areas greater than 74.3 m^2 (800 sq ft).

Maintenance materials include replacement sand for sand lost during bed cleaning, and maintenance and repair components for the front-end loader. Sand replacement costs are based upon an average loss of 1.27 cm/bed cleaning (0.5 in/bed cleaning), a replacement sand cost of $11/metric ton ($10/ton) and a sand density of 1,762 kg/m^3 (110 lb/cu ft). Maintenance and repair items for the front-end loader are based upon $2/hr of operation. Hours per year of front-end loader usage are as described for calculation of diesel fuel requirements.

Labor requirements are equivalent to the hours of front-end loader usage. Operation and maintenance requirements are summarized in Table 147 and are also shown in Figures 140 and 141.

TABLE 147. OPERATION AND MAINTENANCE SUMMARY FOR SAND DRYING BEDS

Total Filter Area, sq ft	Diesel Fuel, gal/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
Five Bed Cleanings/Year				
200	15	40	10	170
500	38	110	25	430
800	60	170	40	680
1,200	68	230	45	800
1,600	90	300	60	1,100
2,000	113	380	75	1,300
Eight Bed Cleanings/Year				
200	24	70	16	270
500	60	170	40	680
800	96	280	64	1,100
1,200	108	360	72	1,300
1,600	144	490	96	1,700
2,000	180	610	120	2,100
Fifteen Bed Cleanings/Year				
200	45	130	30	510
500	113	320	75	1,300
800	180	520	120	2,100
1,200	203	680	135	2,400
1,600	270	910	180	3,200
2,000	338	1,140	225	4,000

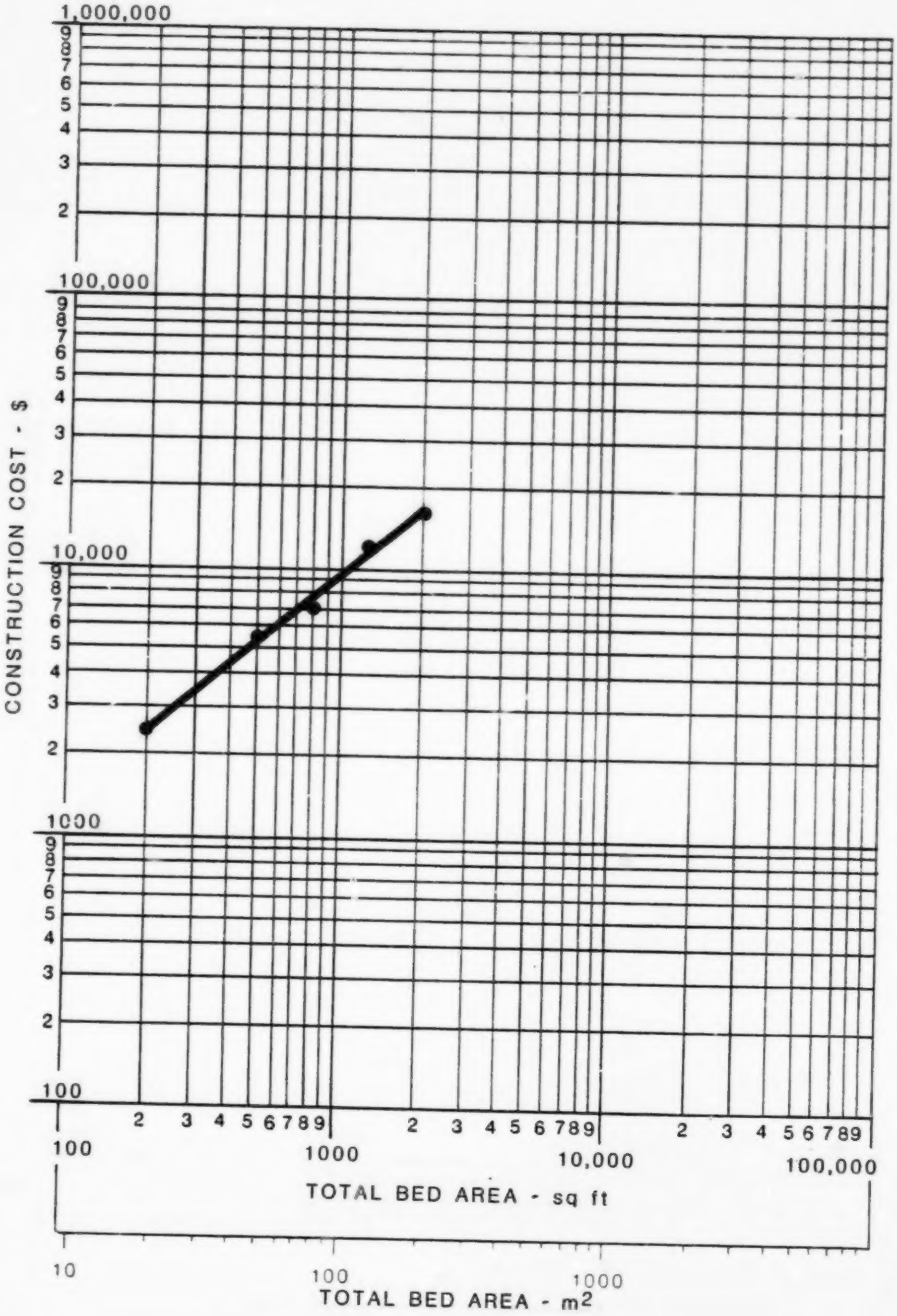


Figure 139. Construction cost for sand drying beds.

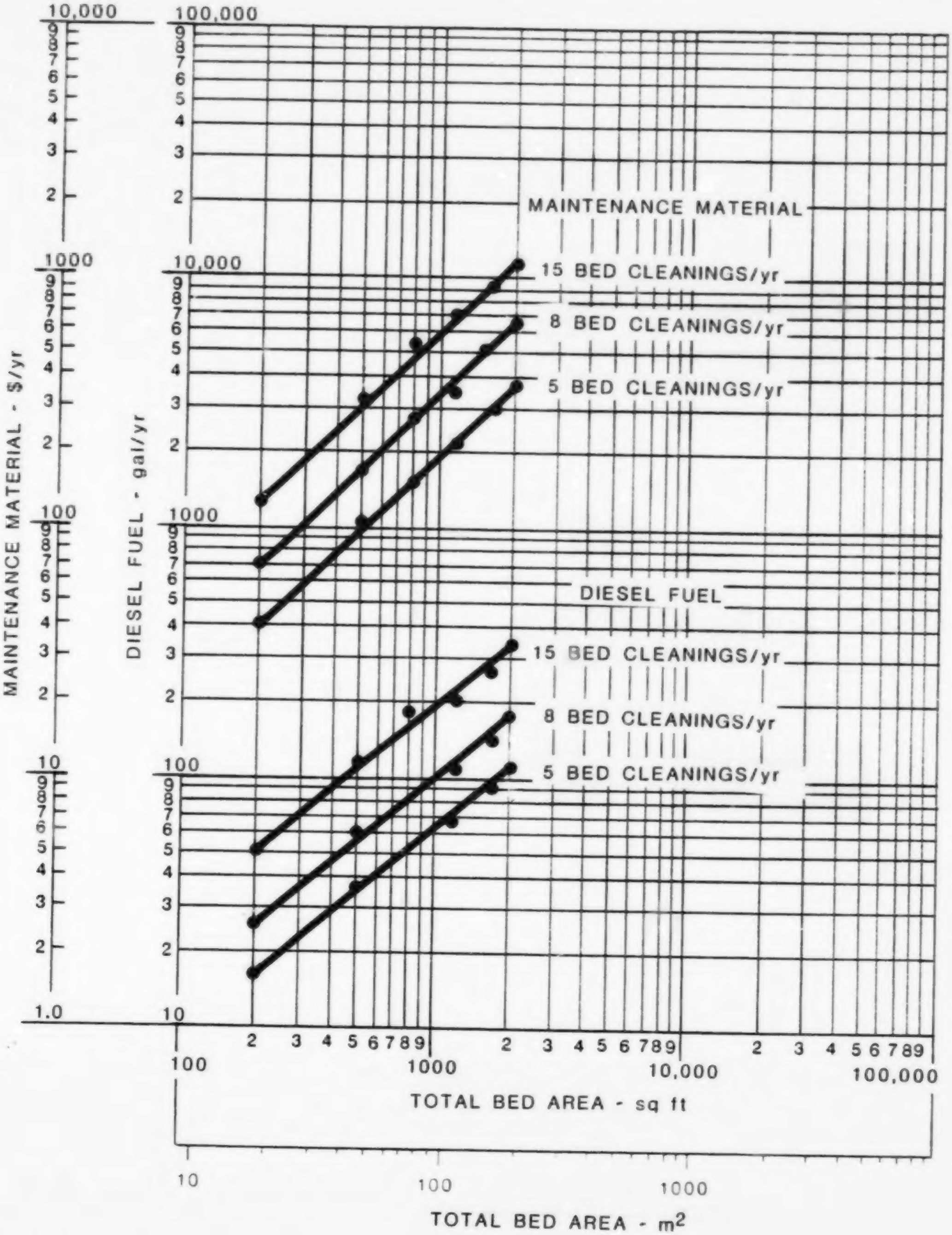


Figure 140. **Operation and maintenance requirements for sand drying beds - diesel fuel and maintenance material.**

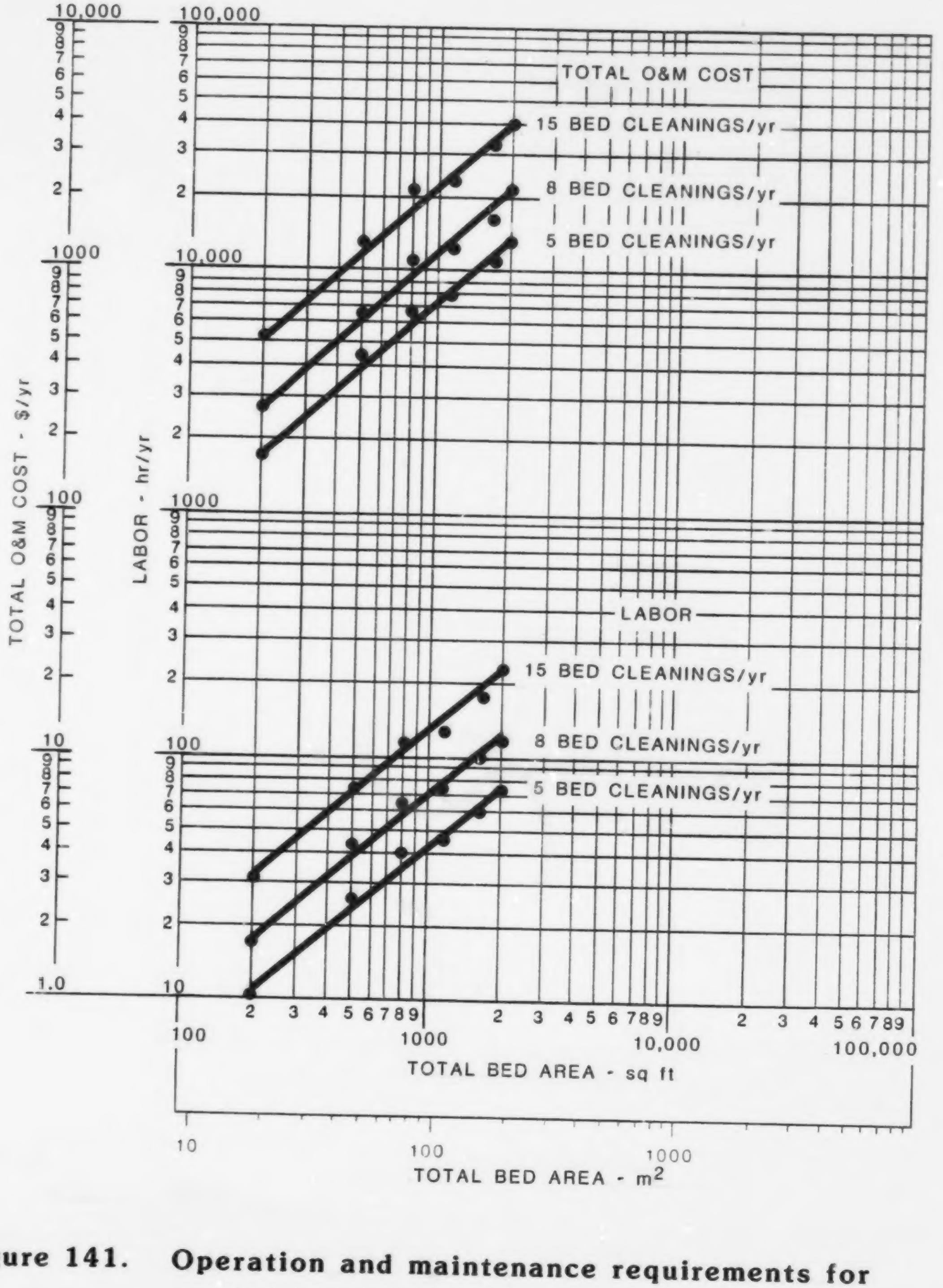


Figure 141. **Operation and maintenance requirements for sand drying beds - labor and total O&M cost.**

LIQUID SLUDGE HAULING BY TRUCK

Introduction

In certain situations, liquid sludge hauling may be used rather than dewatered sludge hauling. Costs for liquid sludge hauling are applicable to sludges with solids concentrations up to about 10%.

Similarly to dewatered sludge hauling, the most economical approach would be to share the tanker truck with another city or agency department. If such sharing is not possible, contract hauling would most likely be the cost-effective approach.

Initial Cost

Initial cost is a function of tanker capacity and whether the truck is gasoline or diesel powered. Diesel powered units are favored because of their fuel economy 3.4-4.3 km/L (8-10 mpg), in contrast to 1.7-2.1 km/L (4-5 mpg) for gasoline powered models. Costs for several different capacity tanker trucks, in both gasoline and diesel versions, are:

Capacity, gal	Gasoline Powered	Diesel Powered
1,600	$41,000	$46,000
2,000	44,000	49,000
2,500	49,000	54,000
3,000	53,000	59,000
4,000	76,000	81,000

These costs include a vacuum/pressure pump on the tanker truck to assist in loading and unloading, and a rear discharge sprayer to be used for land application of sludge.

Operation and Maintenance Requirements and Costs

Fuel usage is variable, depending upon whether the truck is diesel or gasoline powered, and upon the tank capacity. Typical mileages are shown in Table 148.

TABLE 148. TYPICAL MILEAGE AND MAINTENANCE COSTS FOR LIQUID SLUDGE HAULING TRUCKS

Capacity, gal	Mileage, mpg		Maintenance Cost, $/mi
	Diesel	Gas	
1,600	9-10	6	0.10
2,000	8-9	6	0.10
2,500	7-8	5	0.11
3,000	6-7	5	0.11
4,000	5-6	4	0.115

Maintenance items include tires, normal maintenance, lubricants, and vehicle insurance. Typical values for a truck operated (40,000 to 60,000 miles/yr) are shown in Table 148. If the truck is used substantially less than this, the cost per mile traveled would increase due to fewer miles traveled per year.

Labor requirements are for driver time and for time associated with loading and unloading the tanker truck. Requirements per mile traveled decrease as the average speed increases.

Operation and maintenance requirements are summarized in Table 149 and in Figures 142 and 143. This table shows fuel consumption at 2.6, 3.4, and 4.3 km/L (6, 8, and 10 mpg) and labor at average speeds of 24.2, 32.2, and 48.3 km/hr (15, 20, and 30 mph). The total annual cost shown in Table 149 is based upon a fuel consumption of 3.4 km/L (8 mpg), maintenance at $0.093/km ($0.15/mile), and an average travel speed of 32.2 km/hr (20 mph). The formula to use for other conditions is:

$$\$/\text{yr} = \frac{\text{mpy } (\$1.10/\text{gal})}{\text{mpg}} + \text{maint (mpy)} + \left\{\frac{\text{mpy}}{\text{mph}} + \text{rt/yr } (1/\text{ul})\right\} \$11.00/\text{hr}$$

where: mpy = miles/year traveled
mph = average fuel consumption in miles/gallon
maint = maintenance cost in $/mile
mph = average travel speed in miles/hour
rt/yr = round trips/year
1/ul = load and unload time/trip

TABLE 149. OPERATION AND MAINTENANCE SUMMARY FOR LIQUID SLUDGE HAULING

Miles/Year Traveled	Diesel Fuel, gal/yr			Maintenance, $/yr Cost/Mile Traveled		Labor, hr/yr Average Speed, mph			Total Cost, $/yr
	6 mpg	8 mpg	10 mpg	$0.10/mi	$0.15/mi	15	20	30	
100	20	15	10	10	15	8	6	4	100
500	80	65	50	50	75	42	31	21	500
1,000	170	125	100	100	150	83	63	42	1,000
2,500	420	315	250	250	375	208	156	104	2,400
5,000	830	625	500	500	750	417	313	208	4,900
10,000	1,670	1,250	1,000	1,000	1,500	833	625	416	9,800

Notes: 1. Labor includes travel time based upon the average speeds shown, plus a 25 percent allowance for load and unload time.

2. Total cost is based upon a fuel usage of 8 mpg, maintenance of $0.11/mi, and an average travel speed of 20 mph. For other conditions, a formula is presented in the text.

DEWATERED SLUDGE HAULING BY TRUCK

Introduction

Dewatered sludge from sand drying beds or from evaporation lagoons can be hauled to landfill using dump trucks. Generally, a front-end loader would be used to load the dewatered sludge into the dump truck.

For plants less than 3,785 m^3/d (1 mgd), it normally would not be economical to have a truck which would be used solely for sludge hauling. A more likely situation would be a truck shared between various city or agency departments, or even to contract for sludge hauling. If sharing of a truck with other departments is not feasible, contract hauling would be less costly than purchase of a truck specifically for sludge hauling.

Initial Cost

Purchase price for a 2 axle, 4.5 m^3 (6 cu yd) diesel powered dump truck is approximately $35,000. This size truck should be adequate for plant capacities up to 3,785 m^3/d (1 mgd). If sludge hauling is contracted, there would be no initial cost, since the contract would typically be set-up using a unit cost per mile traveled, which would include amortization of the vehicle.

Operation and Maintenance Requirements and Costs

Fuel usage is a function of the mileage achieved. For a 4.5 m^3 (6 cu yd) diesel powered dump truck, mileages typically obtained are 3.4-4.3 km/L (8-10 mpg).

Maintenance items include tires, normal maintenance, lubricants, and vehicle insurance. Typical maintenance costs range between $0.06 and 0.12/km ($0.10 and 0.20/mi). This assumes moderate overall usage of the truck for sludge hauling, as well as other purposes. If the truck were used only for sludge hauling, the cost per mile would be considerably higher due to the relatively low number of miles traveled per year.

Labor requirements are for driver time and for time associated with loading and unloading the dump truck. Requirements per mile traveled decrease as the average speed increases.

Operation and maintenance requirements are summarized in Table 150 and presented in Figures 142 and 143. This table shows fuel consumption at 2.6, 3.4, and 4.3 km/L (6, 8, and 10 mpg) and labor at average speeds of 24.2, 32.2, and 48.3 km/hr (15, 20, and 30 mph). The total annual cost shown in Table 150 is based upon a fuel consumption of 3.4 km/L (8 mpg) and an average travel speed of 32.2 km/hr (20 mph). The formula to use for other conditions is:

$$\$/\text{yr} = \frac{\text{mpy } (\$1.10/\text{gal})}{\text{mpg}} + \text{maint (mpy)} + \left\{\frac{\text{mpy}}{\text{mph}} + \text{rt/yr (l/ul)}\right\} \$11.00/\text{hr}$$

where: mpy = miles/year traveled
mph = average fuel consumption in miles/gallon
maint = maintenance cost in $/mile
mph = average travel speed in miles/hour
rt/yr = round trips/year
l/ul = load and unload time/trip

TABLE 150. OPERATION AND MAINTENANCE SUMMARY FOR DEWATERED SLUDGE HAULING

Miles/Year Traveled	Diesel Fuel, gal/yr			Maintenance, $/yr Cost/Mile Traveled			Labor, hr/yr Average Speed, mph			Total Cost, $/yr
	6 mpg	8 mpg	10 mpg	$0.10/mi	$0.15/mi	$0.20/mi	15	20	30	
100	20	15	10	10	15	20	8	6	4	100
500	80	65	50	50	75	100	42	31	21	500
1,000	170	125	100	100	150	200	83	63	42	1,000
2,500	420	315	250	250	375	500	208	156	104	2,400
5,000	830	625	500	500	750	1,000	417	313	208	4,900
10,000	1,670	1,250	1,000	1,000	1,500	2,000	833	625	416	9,800

Notes: 1. Labor includes travel time based upon the average speeds shown, plus a 25 percent allowance for load and unload time.

2. Total cost is based upon a fuel usage of 8 mpg, maintenance of $0.15/mi, and an average travel speed of 20 mph. For other conditions, a formula is presented in the text.

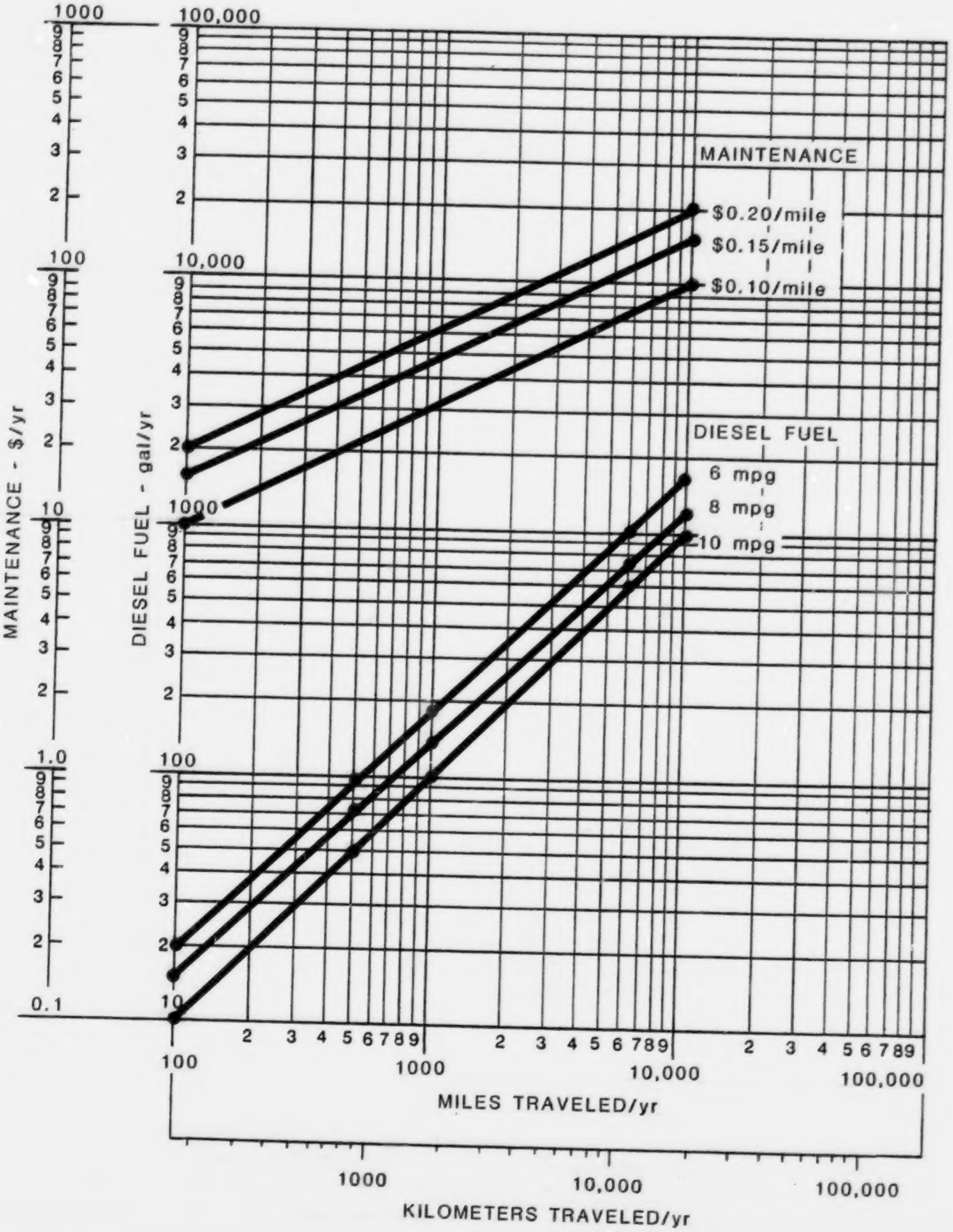


Figure 142. **Operation and maintenance requirements for liquid and dewatered sludge hauling.**

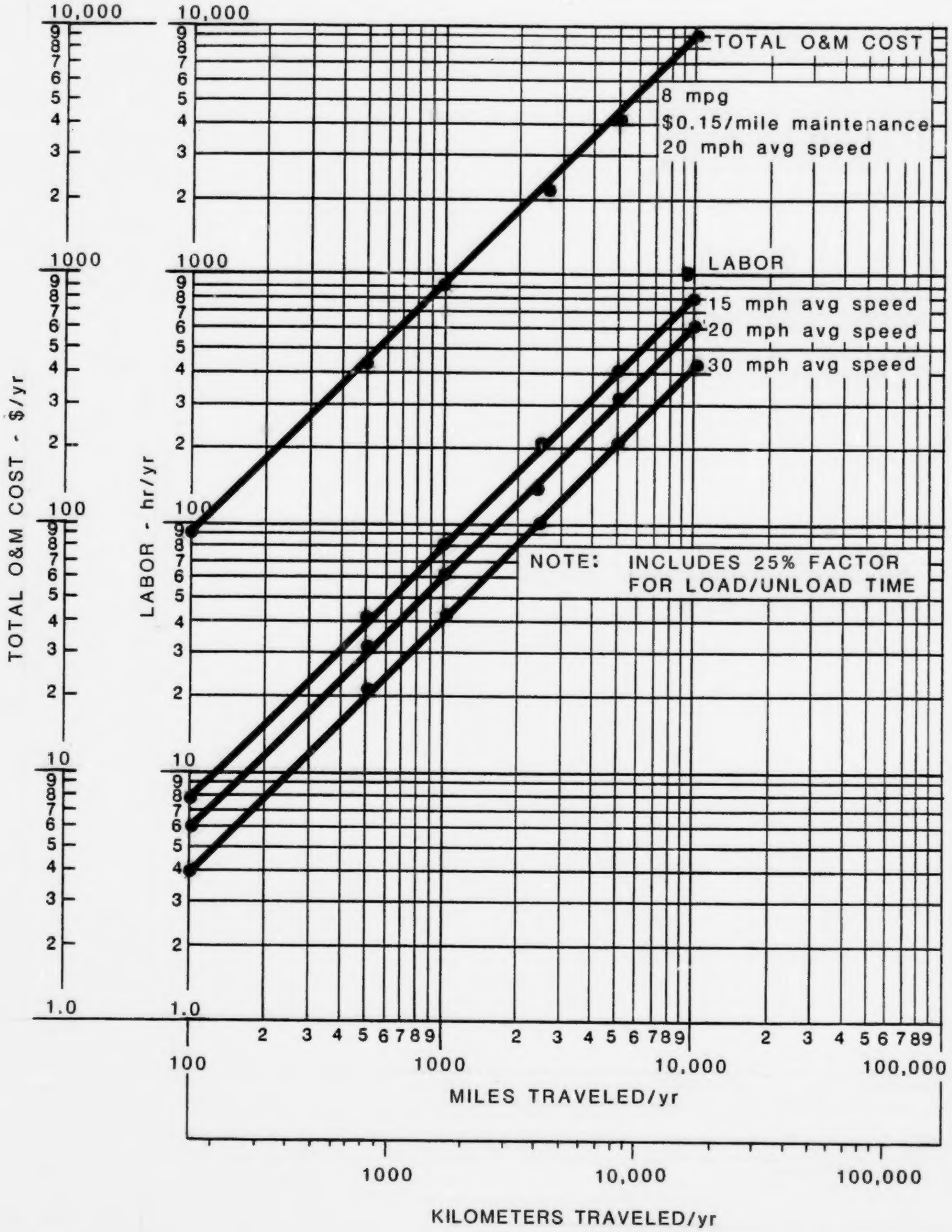


Figure 143. Operation and maintenance requirements for liquid and dewatered sludge hauling - labor and total O&M cost.

BRINE EVAPORATION LAGOONS

Introduction

Ion exchange and activated alumina treatment produce liquid wastes which in some cases can not be discharged to the sanitary sewer system, either due to the lack of such a system or due to restrictions on discharge to the system. An alternative method of disposal of these wastes is evaporation lagoons. Design of such lagoons is very site specific, with the required surface area depending upon the type of waste, local climate conditions, and whether or not the ponds are lined.

Construction Costs

Evaporation lagoons are constructed using earth berms on a 2:1 slope. Inlet piping and valves are included, as is an overflow pipe which could be used in emergency conditions. Earthwork costs were developed assuming that the volume of material excavated is equivalent to the volume of fill. Conceptual designs for four different size lagoons are presented in Table 151. All lagoons are 1.22 m (4 ft) deep, including 0.61 m (2 ft) of freeboard.

TABLE 151. CONCEPTUAL DESIGNS FOR BRINE EVAPORATION LAGOONS

Lagoon Surface Area, sq ft	Lagoon Surface Area, acres	Effective Storage Volume, cu ft	Number of Lagoons	Lagoon Dimensions, ft length	Lagoon Dimensions, ft width	Plastic Liner Area, sq ft
3,500	0.08	14,000	2	40	40	5,800
34,900	0.80	69,800	2	130	130	41,400
100,000	2.3	200,000	2	250	250	114,200
348,500	8.0	697,000	4	300	300	394,300
653,400	15.0	1,306,800	4	400	400	685,400

Depending upon the local soil types and groundwater considerations, sealing of the bottom and sides of the lagoons with a plastic liner may be necessary. Construction costs presented in Table 152 and Figure 144 are for lagoons with and without a plastic liner.

Operation and Maintenance Requirements and Costs

Maintenance material includes repair components for the inlet valve(s) and weed control chemicals for control of weeds on the inner slope of the dikes of the lagoons without plastic liners. When a plastic liner is used, it was assumed that the liner itself would preclude any weed growth.

Labor requirements are for annual overhaul of the inlet valve(s), annual cleaning of the overflow pipe, and weed control for the unlined lagoons. Operation and maintenance requirements are summarized in Table 153 and presented in Figure 145 for lagoons with and without liners.

TABLE 152. CONSTRUCTION COST SUMMARY FOR BRINE EVAPORATION LAGOONS

Cost Category	Lagoon Surface Area, sq ft				
	3,500	34,900	100,000	348,500	653,400
Lagoons Without Plastic Liner					
Excavation and Sitework	$ 7,500	$26,000	$ 63,000	$182,500	$303,000
Concrete	100	100	100	200	200
Steel	100	100	100	100	100
Labor, Installation	1,100	2,300	4,200	10,300	13,100
Pipe and Valves	1,700	2,600	44,000	10,200	12,200
Subtotal	10,500	31,100	71,800	203,300	328,600
Design Contingencies	1,600	4,700	10,800	30,500	49,300
Total	$12,100	$35,800	$82,600	$233,800	$377,900
Lagoons With Plastic Liner					
Excavation and Sitework	$ 7,500	$26,000	$ 63,000	$182,500	$303,000
Plastic Liner	4,600	22,800	62,800	157,700	274,200
Concrete	100	100	100	200	200
Steel	100	100	100	100	100
Labor, Installation	1,100	2,300	4,200	10,300	13,100
Pipe and Valves	1,700	2,600	4,400	10,200	12,200
Subtotal	15,100	53,900	134,600	361,000	602,800
Design Contingencies	2,300	8,100	20,200	54,200	90,400
Total	$17,400	$62,000	$154,800	$415,200	$693,200

TABLE 153. OPERATION AND MAINTENANCE SUMMARY FOR BRINE EVAPORATION LAGOONS

Lagoon Surface Area, sq ft	Maintenance Material, $/yr		Labor, hr/yr		Total Cost, $/yr	
	Liner	No Liner	Liner	No Liner	Liner	No Line
3,500	$100	$ 150	20	28	$300	$ 550
34,900	100	200	20	40	300	800
100,000	100	300	20	52	300	900
348,500	200	700	40	120	800	2,500
653,400	200	1,200	40	140	800	3,300

Note: Total cost is based on $11.00/hour of labor.

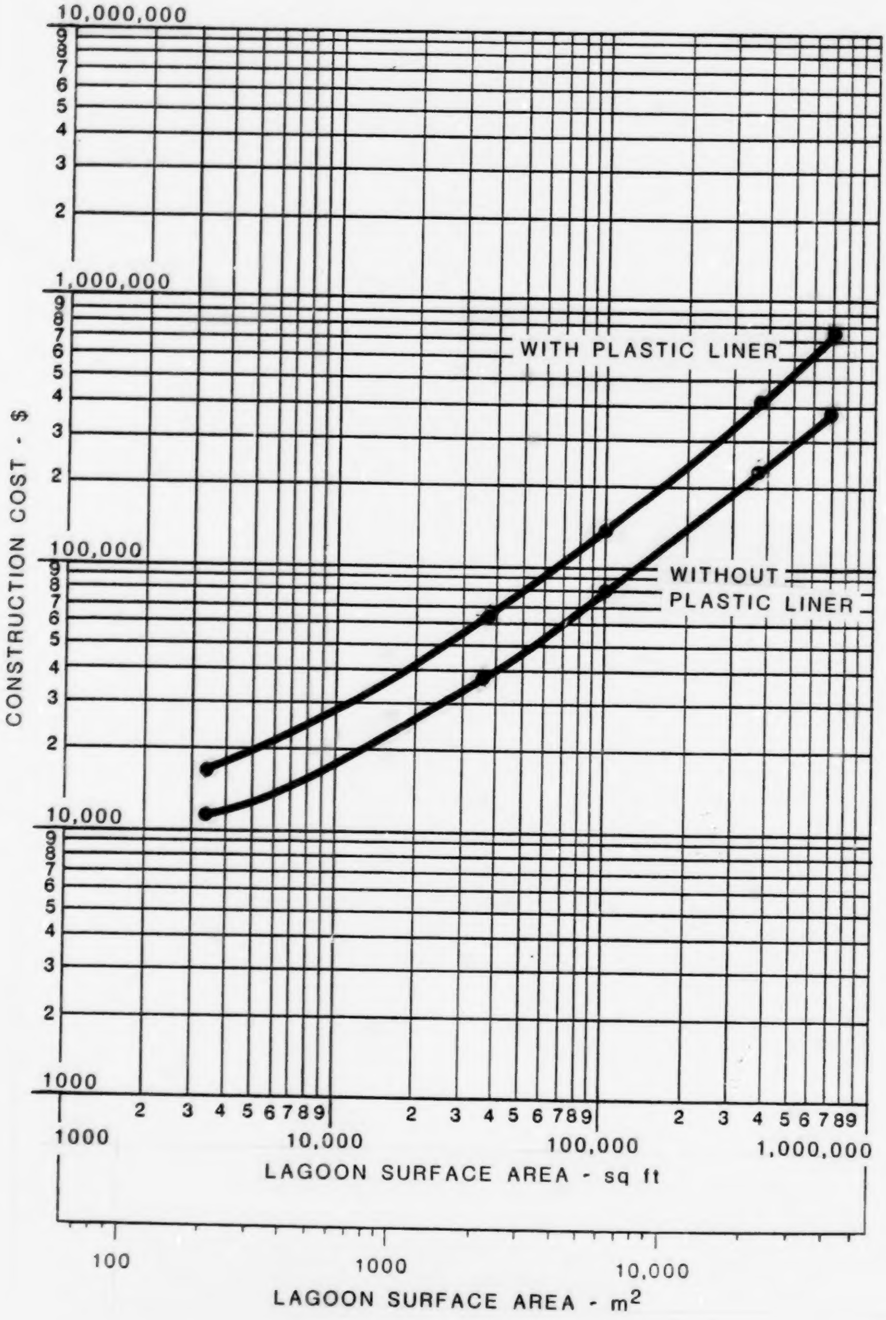


Figure 144. **Construction cost for brine evaporation lagoons.**

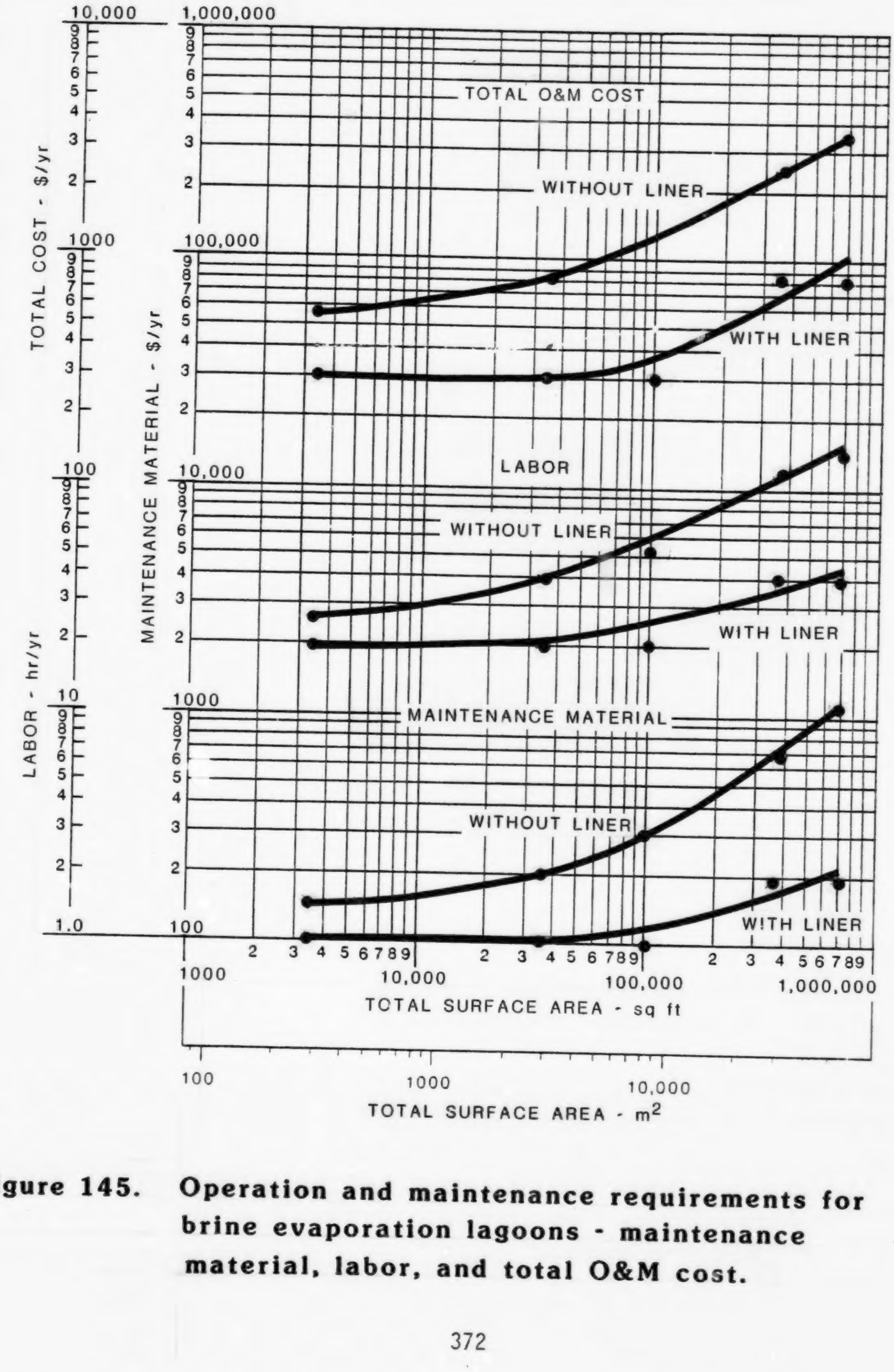


Figure 145. **Operation and maintenance requirements for brine evaporation lagoons - maintenance material, labor, and total O&M cost.**

WATER WELLS

Introduction

Water wells are drilled by the cable tool, hydraulic rotary or reverse rotary methods, with hydraulic rotary currently the most common method. Construction of these types of water wells is covered by "American Water Works Association Standard for Deep Wells, AWWA A100-66" and by "Manual of Water Well Construction Practices, EPA-570/9-75-001."[1,2]

Construction of water wells by the hydraulic rotary method takes place in the following sequence:

1. Install protective casing and grout in place for sanitary seal.
2. Drill 15.2 to 30.5 cm (6 to 12 in) diameter pilot hole.
3 Electric log pilot hole to help determine location of water bearing formations.
4. Ream hole to required diameter and depth.
5. Install blank and perforated casing or well screen.
6. Place gravel pack and grout seals.
7. Develop well by pumping and bailing.
8. Conduct pumping test to verify capacity before permanent pump is installed.
9. Install pump and construct enclosure.

Conceptual design criteria for wells are shown in Table 154 and a cross-section for a typical well is shown in Figure 146.

TABLE 154. CONCEPTUAL DESIGNS FOR WATER WELLS

Well Capacity,		Casing Diameter,	Well Depth,	Pump Motor Size,	Enclosure,
gal/day	gal/min	in	ft	hp	sq ft
144,000	100	8	250	10	40
			500	20	
432,000	300	10	250	25	60
			500	50	
720,000	500	12	250	40	80
			500	75	
1,008,000	700	16	250	50	100
			500	100	

Notes: 1. Maximum pumping depth 50-100 ft less than well depth.
2. Enclosure has a 10 ft height.

Construction Costs

Construction costs were developed for water well construction by the hydraulic rotary method, as outlined in the previous section. The protective casing and grout was installed to a depth of 7.62 m (25 ft). Casing is blank and perforated copper bearing steel, with gravel packing and grout seals. After construction, the well is developed by bailing and pumping to remove drilling mud, silt and fine sand. The completed well is then test pumped until the water has sufficient clarity for potable use. This often requires pumping for up to 60 hours.

The permanent pump is the oil lubricated, deep-well turbine type and the electric motor is 220/440 volt. A submersible type pump at somewhat reduced cost could be used in some cases, particularly for shallow, small capacity wells. Pump motor sizes and casing diameter used in the cost development are shown in Table 154.

The electrical cost includes all work required at the well but does not include providing service to the site. Costs include a valve and totalizing flow meter on the discharge, but no other piping or equipment. An enclosure is provided over the motor, totalizing meter, and valve.

Construction costs are summarized in Table 155 and presented in Figure 147 for wells capable of producing 545, 1,635, 2,725, and 3,815 m^3/d (144,000, 432,000, 720,000 and 1,008,000 gpd) from wells 76.2 and 152.4 m (250 and 500 ft) deep.

Operation and Maintenance Requirements and Costs

Electricity requirements are based on continuous operation of the motor, at a pumping head 15.24 m (50 ft) less than the well depth. No energy is included for the housing, as it was assumed that heating and ventilation are unnecessary, and that lighting requirements are minimal. Many wells do not operate continuously and in these cases the energy requirements will be reduced according to the actual load factor. Material requirements are based on necessary lubricants and other routine maintenance items and servicing the pump and motor once in five years. Labor requirements are based on daily visits for inspection and routine maintenance. Labor and material required to remove and service the pump and motor once every five years are included in the average annual values.

Operation and maintenance requirements and costs are summarized in Table 156 and presented in Figures 148 and 149.

References

1. "AWWA Standard for Deep Wells," AWWA A100-66, January 23, 1966, American Water Works Association, 2 Park Avenue, New York, N. Y. 10016

2. "Manual of Water Well Construction Practices," EPA-570/9-75-001, U.S. Environmental Protection Agency, Office of Water Supply, Washington, D.C.

TABLE 155. CONSTRUCTION COST SUMMARY FOR WATER WELLS

	Well Capacity							
	144,000 gpd		432,000 gpd		720,000 gpd		1,008,000 gpd	
	Well Depth		Well Depth		Well Depth		Well Depth	
Cost Category	250 ft	500 ft	250 ft	500 ft	250 ft	500 ft	250 ft	500 ft
Excavation & Sitework	$ 1,100	$ 1,100	$ 1,600	$ 1,600	$ 2,100	$ 2,100	$ 2,700	$ 2,700
Manufactured Equipment	10,300	13,400	15,500	18,500	18,500	21,600	21,600	25,800
Concrete	1,600	2,900	1,800	3,100	2,000	3,200	2,100	40,900
Labor	17,300	33,200	19,000	36,200	20,800	39,300	22,500	42,400
Pipe & Valves	5,600	10,300	7,500	13,300	9,200	16,100	12,900	23,000
Electrical, Instrumentation	7,700	10,100	11,600	13,900	13,900	16,200	16,200	19,300
Housing	3,400	3,400	4,700	4,700	6,100	6,100	10,100	10,100
Subtotal	47,000	74,400	61,700	91,300	72,600	104,600	88,100	164,200
Design Contingencies	7,100	11,200	9,300	13,700	10,900	15,700	13,200	24,600
Total	$54,100	$85,600	$71,000	$105,000	$83,500	$120,300	$101,300	$188,800

TABLE 156. OPERATION AND MAINTENANCE SUMMARY FOR WATER WELLS

Well Capacity, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
Well Depth - 250 ft						
144,000	--	44,100	44,100	1,300	450	9,300
432,000	--	132,000	132,000	1,800	500	16,600
720,000	--	220,200	220,200	2,300	550	23,800
1,008,000	--	308,300	308,300	2,700	600	30,900
Well Depth - 500 ft						
144,000	--	99,700	99,100	1,800	500	14,300
432,000	--	297,300	297,300	2,500	550	29,400
720,000	--	495,600	495,600	2,800	600	44,100
1,008,000	--	693,700	693,700	3,300	650	59,000

Notes:
1. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.
2. Pumping heads are 200 ft for the 250 ft deep well, and 450 ft for the 500 ft deep well.
3. Pumping is continuous, 24 hours/day, 365 days/year.

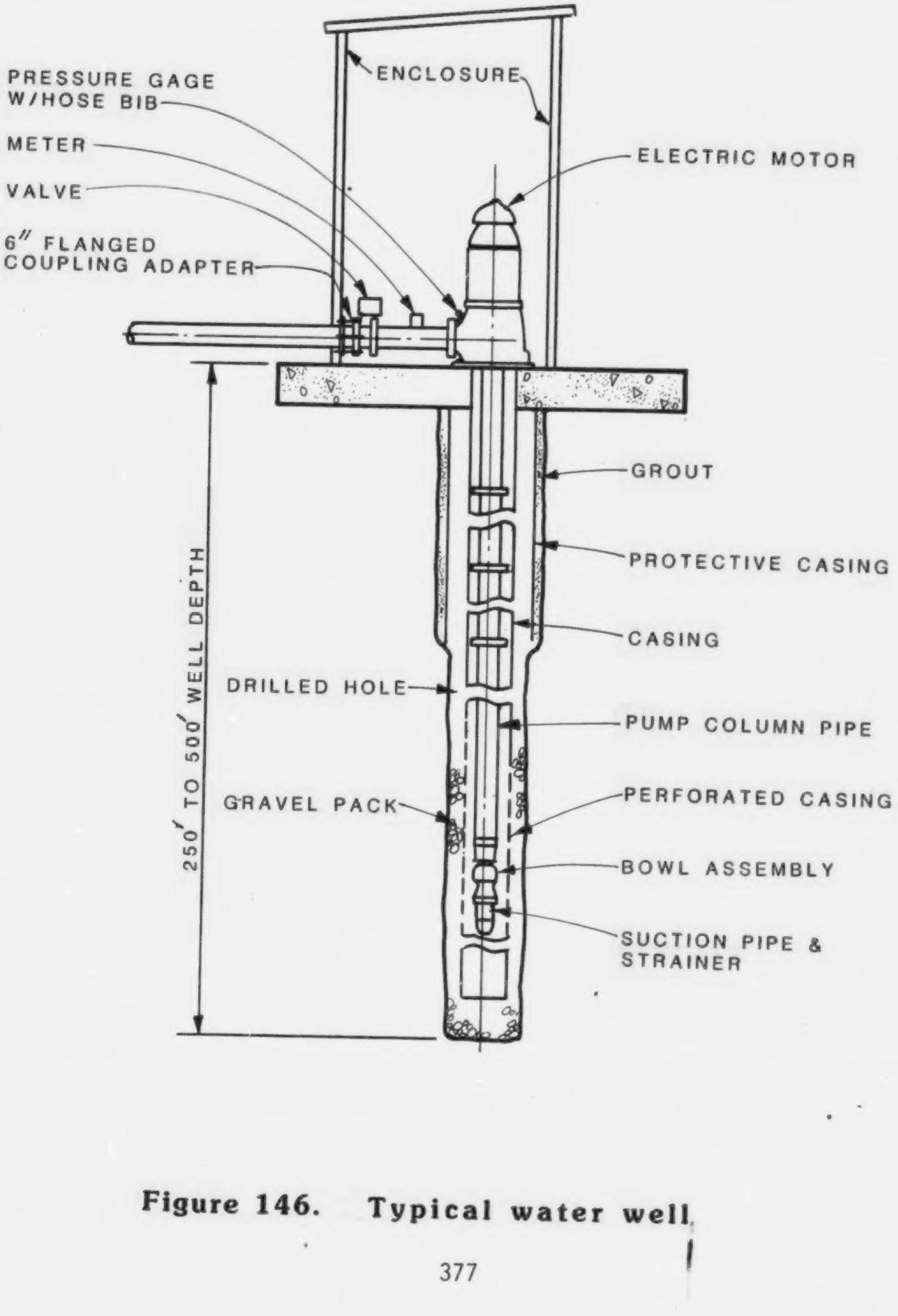

PRESSURE GAGE W/HOSE BIB
METER
VALVE
6" FLANGED COUPLING ADAPTER
ENCLOSURE
ELECTRIC MOTOR
GROUT
PROTECTIVE CASING
CASING
DRILLED HOLE
PUMP COLUMN PIPE
GRAVEL PACK
PERFORATED CASING
BOWL ASSEMBLY
SUCTION PIPE & STRAINER
250' TO 500' WELL DEPTH

Figure 146. Typical water well

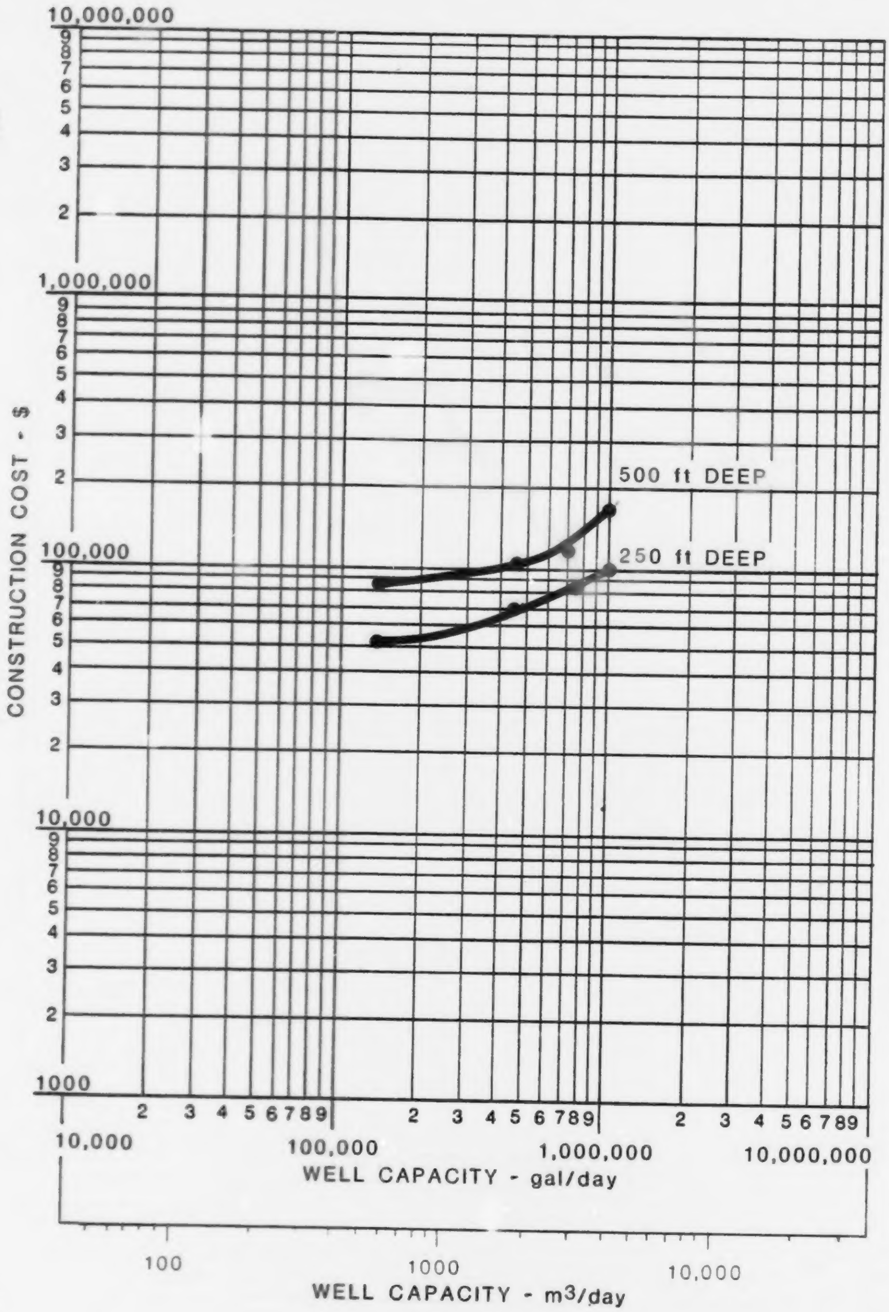


Figure 147. Construction cost for water wells.

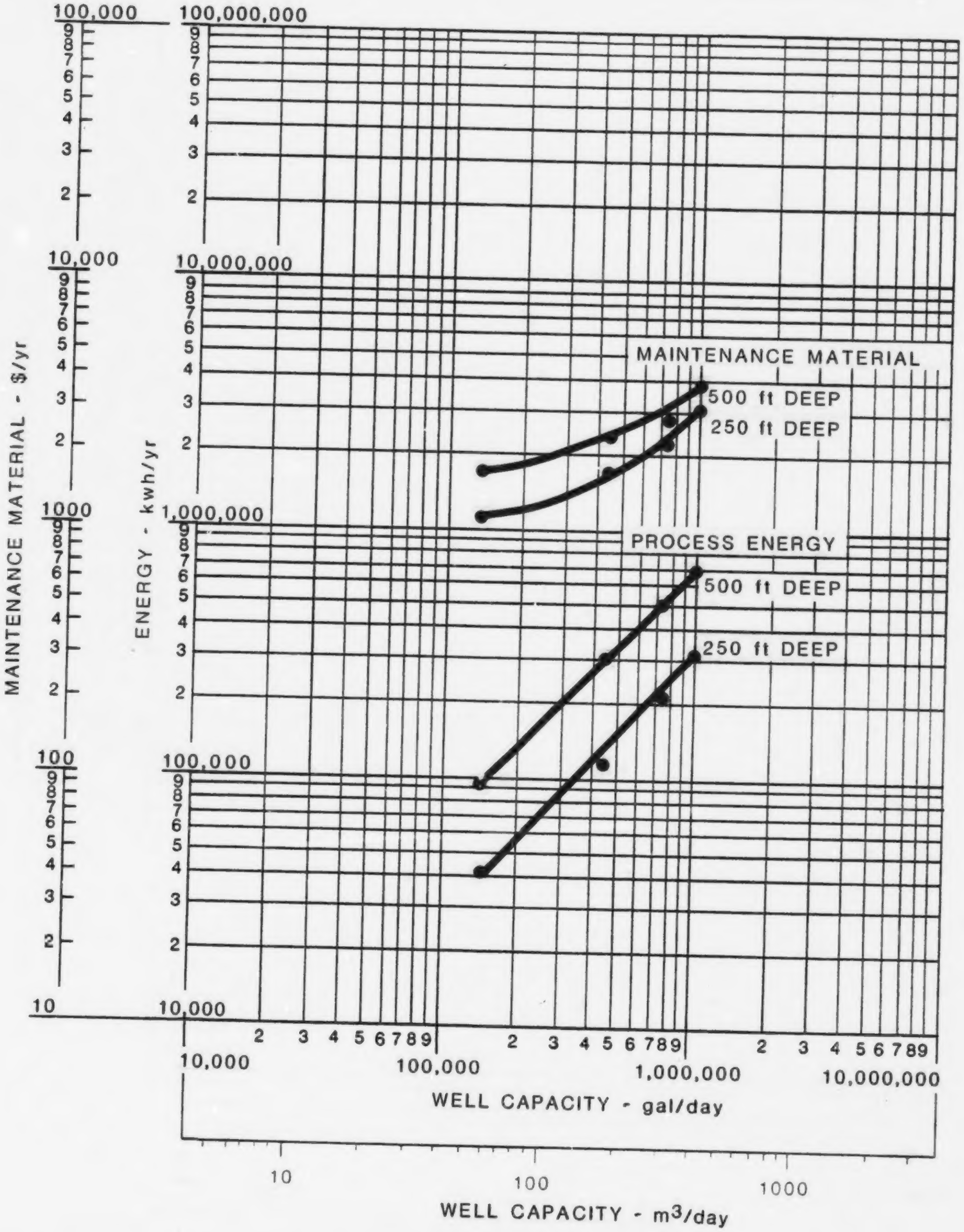


Figure 148. **Operation and maintenance requirements for water wells - process energy and maintenance material.**

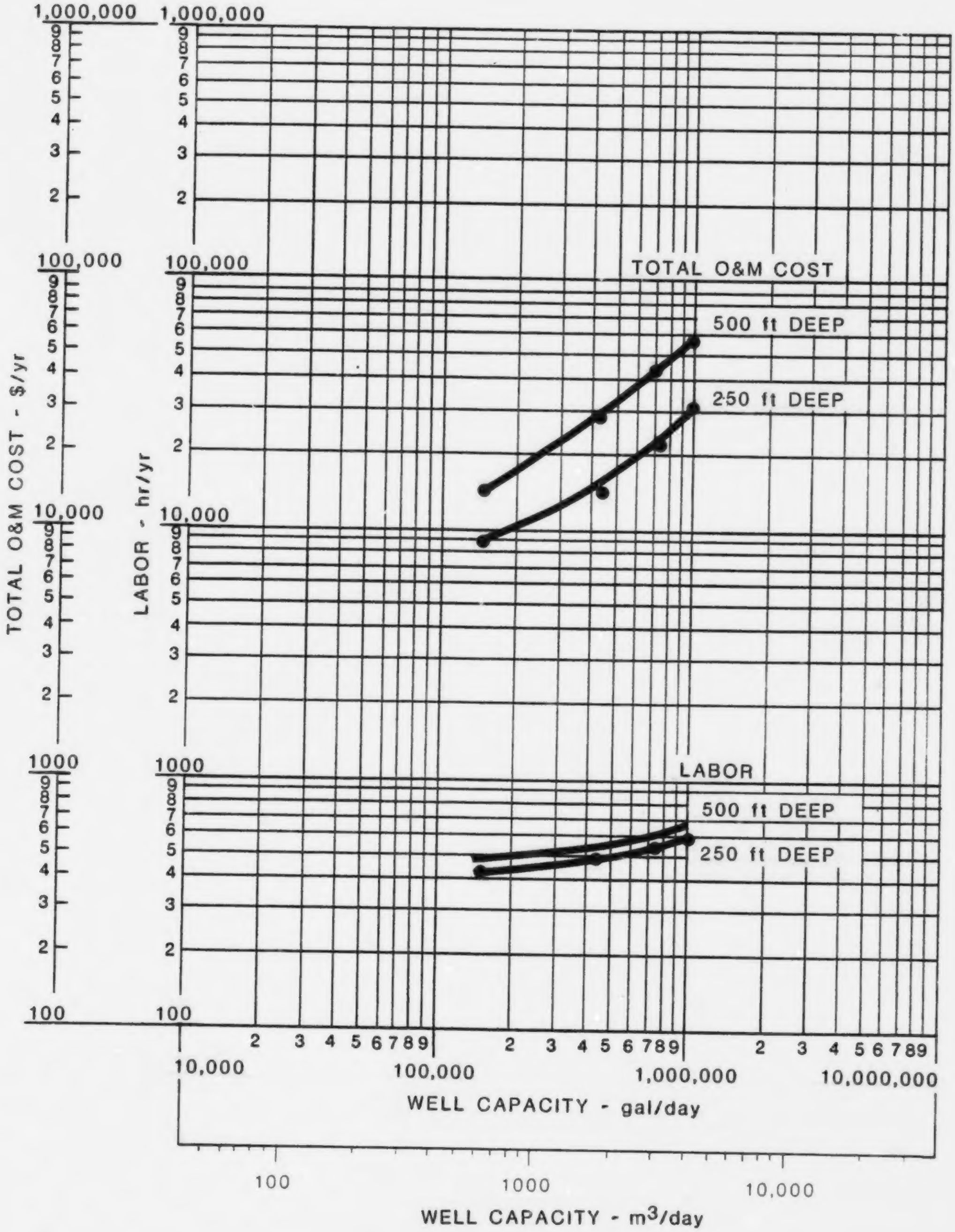


Figure 149. **Operation and maintenance requirements for water wells - labor and total O&M cost.**

PACKAGE RAW WATER PUMPING FACILITIES

Construction Costs

Construction cost estimates were developed for raw water pumping facilities with capacities from 109 to 3,815 m^3/d (28,800 to 1,008,000 gpd). Costs were based on the use of premanufactured package stations using duplex submersible pumps contained in a 6.1 m (20 ft) deep steel pump sump. This pump sump would be covered, and includes an entry hatch and ladder rungs for operator access. The pump sump is supported on a concrete anchor slab at the bottom of the excavation. The pumping facilities are located adjacent to a stream or lake, and water enters the pump station by gravity flow from the intake structure. A typical package raw water pumping facility is illustrated in Figure 150.

The costs include the pump sump, the premanufactured package pump station, manifold piping within the sump, sump intake line valve, pump check valves, and electrical controls. Excavation costs are based upon a 1:1 side slope, an allowance for dewatering, and backfill compaction. Main electrical control panels are included in the cost estimate, and these panels are assumed to be located in the treatment plant control building. Excluded are costs of the raw water intake structure, and transmission lines between water source and pump sump and between the pump sump and the treatment facilities. Costs of these items are excluded because specific site conditions will result in significant variations in requirements and cost. No housing for the pumping facilities is required.

Estimated construction costs are shown in Table 157 for facilities capable of pumping against a head of 15.2 to 30.5 m (50 to 100 ft). The costs are graphically presented in Figure 151.

Operation and Maintenance Requirements and Costs

Process electrical energy requirements are for continuous, 24-hour per day operation of raw water pumps at a TDH of 15.2 m (50 ft). Power requirements were based on a pumping efficiency of 80 percent and a motor efficiency of 90 percent. Since the facilities are not in a building, no energy for heating or ventilating is required. Lighting requirements in the sump are minimal and are not included.

Annual maintenance material requirements for submersible pumps, valves, and electrical equipment were estimated at 1 percent of the construction cost of these items.

Labor requirements are for general maintenance of pumping station equipment. Maintenance requirements for the totally sealed submersible pumps are minimal.

Operation and maintenance requirements are summarized in Table 158 and illustrated in Figures 152 and 153.

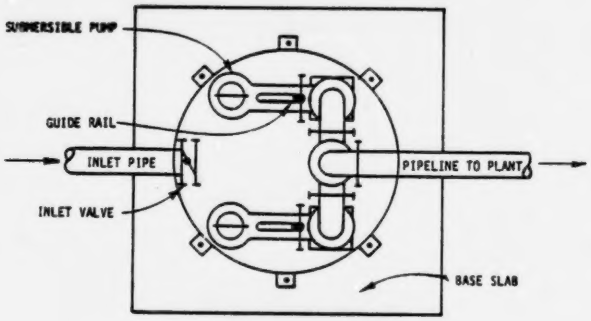
TABLE 157. CONSTRUCTION COST SUMMARY FOR PACKAGE RAW WATER PUMPING FACILITIES

Cost Category	Pumping Capacity in gpd at TDH of 50 ft				
	28,800	144,000	504,000	720,000	1,008,000
Excavation and Sitework	$11,700	$11,700	$12,300	$12,300	$12,800
Manufactured Equipment	6,600	7,800	11,800	12,600	16,500
Concrete	500	500	1,100	1,100	1,500
Labor, Installation	3,700	3,800	5,800	6,200	8,500
Pipe and Valves	1,500	1,800	2,700	3,600	4,500
Electrical, Instrumentation	800	800	1,400	1,600	2,100
Subtotal	24,800	26,400	35,100	37,400	45,900
Design Contingencies	3,700	4,000	5,300	5,600	6,900
Total	$28,500	$30,400	$40,400	$43,000	$52,800

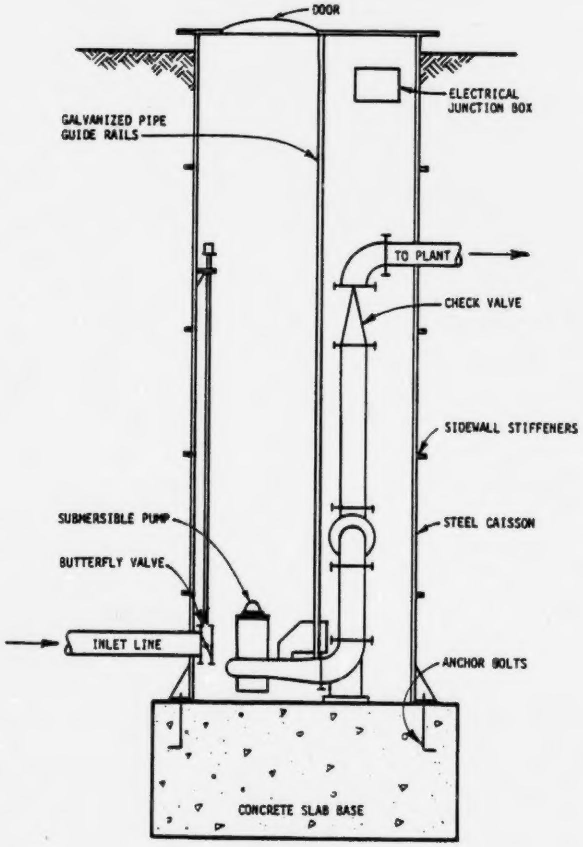
TABLE 158. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE RAW WATER PUMPING FACILITIES

Plant Capacity, gpd	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
28,800	2,300	100	50	800
144,000	11,600	140	60	1,600
504,000	40,700	200	80	3,900
720,000	58,000	230	100	5,400
1,008,000	81,300	270	120	7,300

Notes: 1. Continuous 24-hr/day, 365-day/yr operation is assumed.
2. Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.


SUBMERSIBLE PUMP
GUIDE RAIL
INLET PIPE
INLET VALVE
PIPELINE TO PLANT
BASE SLAB

PLAN


DOOR
ELECTRICAL JUNCTION BOX
GALVANIZED PIPE GUIDE RAILS
TO PLANT
CHECK VALVE
SIDEWALL STIFFENERS
STEEL CAISSON
SUBMERSIBLE PUMP
BUTTERFLY VALVE
INLET LINE
ANCHOR BOLTS
CONCRETE SLAB BASE

ELEVATION

Figure 150. Typical package raw water pumping facility.

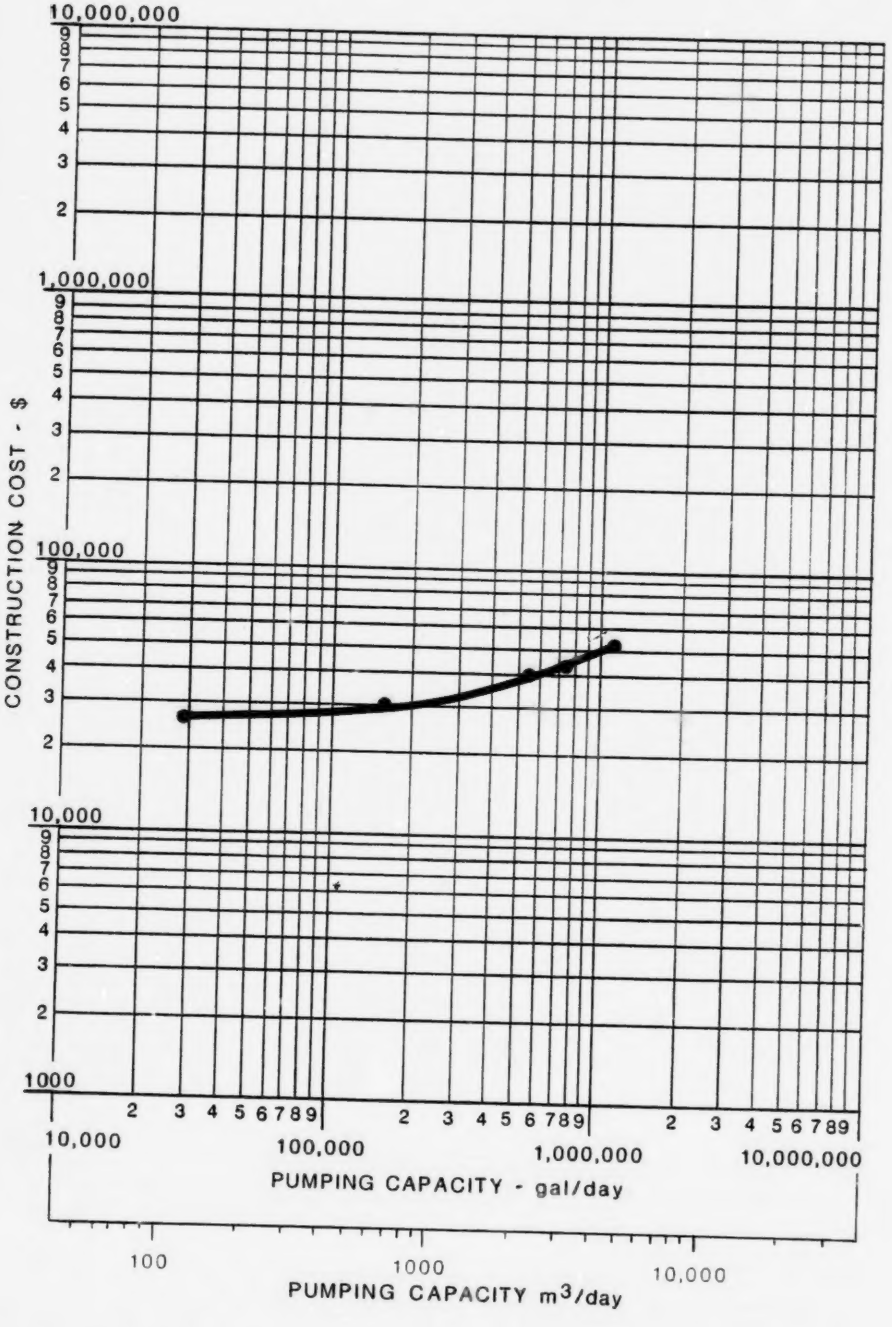


Figure 151. Construction cost for package raw water pumping stations.

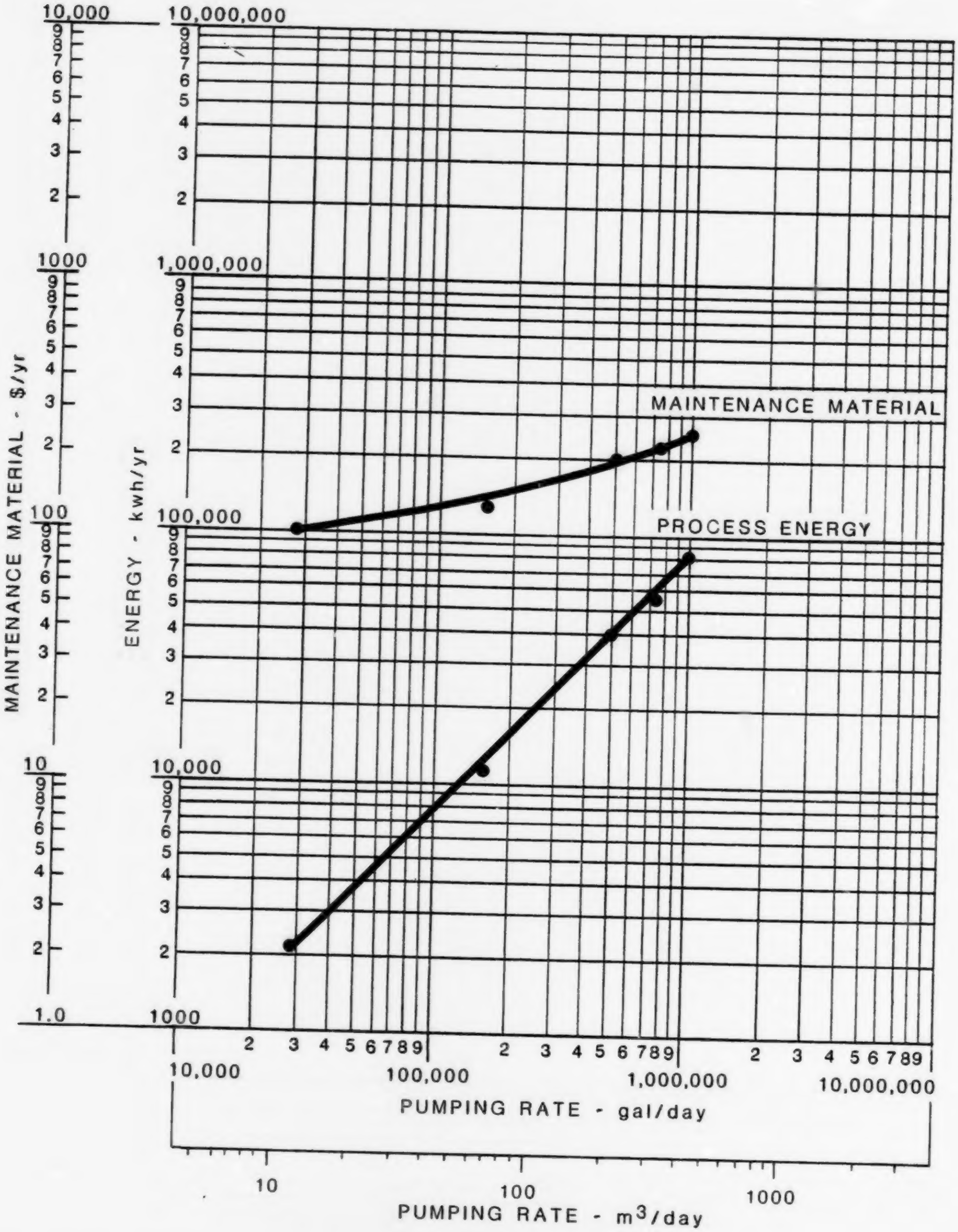


Figure 152. Operation and maintenance requirements for package raw water pumping stations - process energy and maintenance material.

26A

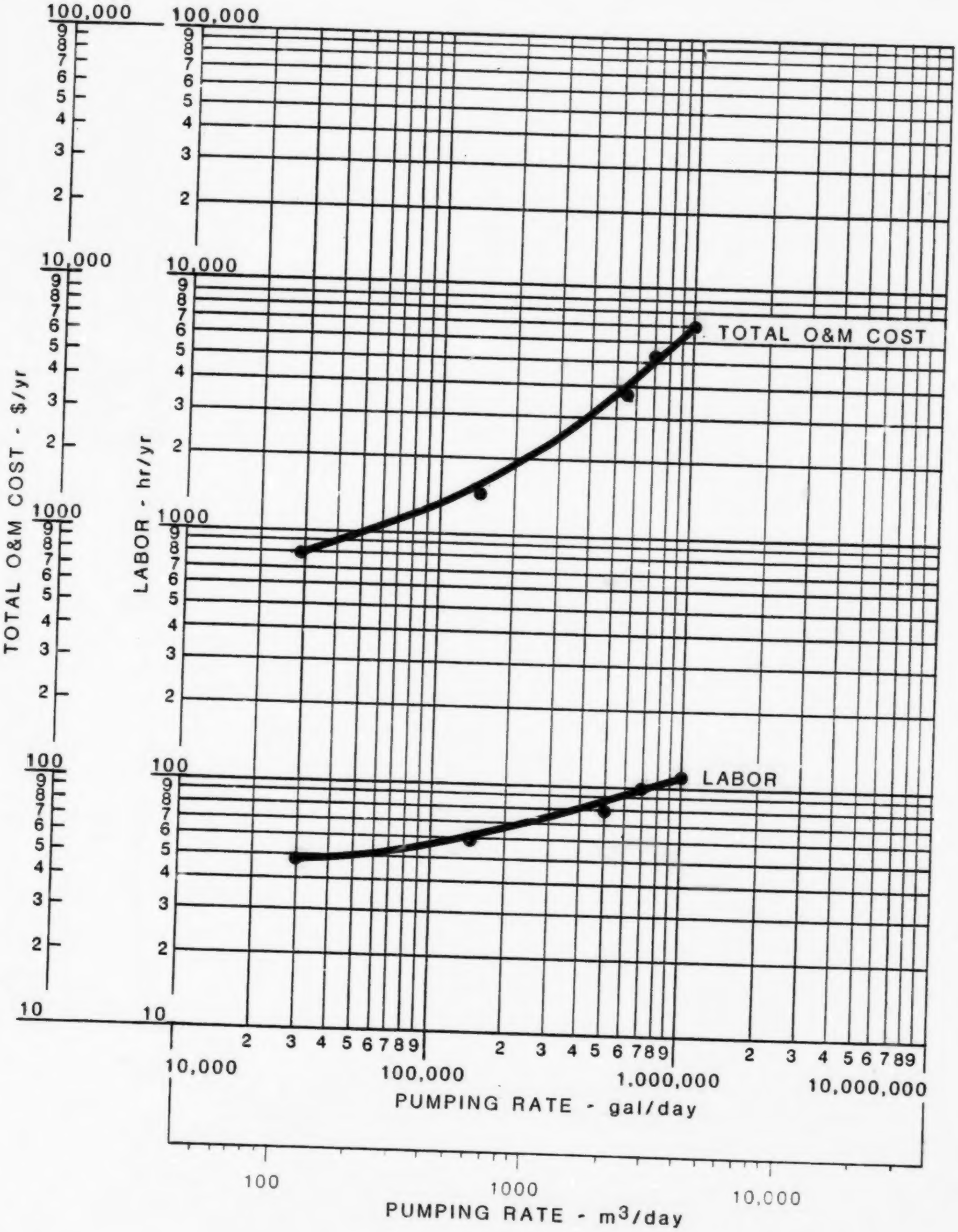


Figure 153. **Operation and maintenance requirements for package raw water pumping stations - labor and total O&M cost.**

26B

PACKAGE HIGH-SERVICE PUMPING FACILITIES

Construction Costs

Package finished water pumping stations may be suitable for use with certain small systems. Such stations are capable of handling wide variations in flow typically experienced in small systems due to fluctuating system demand, at the same time maintaining relatively uniform system pressure. Costs were developed for single units ranging in size from 164 to 10,900 m^3/d (43,200 to 2,880,000 gpd) to match expected maximum system hourly demands from plants producing 37.9 to 3,785 m^3/d (10,000 gpd to 1 mgd). Pumps were selected to provide a maximum output pressure of 4.92 kg/cm^2 (70 psi). The units are designed for flooded suction applications and are to be used with above-grade storage tanks.

Pumping stations utilize two end suction centrifugal pumps for capacities smaller than 2,180 m^3/d (576,000 gpd), and three such pumps are used to handle flows in excess of 2,180 m^3/d (576,000 gpd). The pumping stations are prepackaged and contain pumps, pressure sensing and flow control valves, and required electrical equipment and instrumentation.

No allowance for housing costs was included, since spatial requirements are minimal, and adequate floor area within treatment plant structures is generally available. Also, storage tank costs are not included.

Figure 154 and Table 159 present construction costs for package high-service pumping stations.

Operation and Maintenance Requirements and Costs

Pumping units were selected to handle peak hourly flows and utilize a two or three-pump system with a lead pump and one or two main pumps. In all systems, continuous 24-hr operation of the lead pump and 8-hr operation of the main pump was assumed to determine energy usage. Pumping costs were computed based on supplying the indicated flows at 4.92 kg/cm^2 (70 psi) discharge pressure.

TABLE 159. CONSTRUCTION COST SUMMARY FOR PACKAGE HIGH-SERVICE PUMPING STATIONS

Cost Category	Pumping Capacity, gpd				
	43,200	144,000	360,000	1,440,000	2,880,000
Manufactured Equipment	$ 8,800	$11,100	$14,400	$25,800	$33,000
Labor, Installation	1,800	2,300	2,800	6,200	7,900
Pipe and Valves	600	700	900	2,000	3,600
Electrical, Instrumentation	1,800	1,800	2,300	3,600	4,300
Subtotal	13,000	15,900	20,400	37,600	48,800
Design Contingencies	2,000	2,400	3,100	5,600	7,300
Total	$15,000	$18,300	$23,500	$43,200	$56,100

Maintenance material costs are related to replacement costs for seals and other miscellaneous small parts. Labor requirements consist of pump seal lubrication, occasional seal replacement and calibration of pressure control devices.

Operation and maintenance requirements for package high-service pumping stations are listed in Table 160 and illustrated in Figures 155 and 156.

TABLE 160. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE HIGH-SERVICE PUMPING STATIONS

Average Flow Rate, gpd	Process Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
43,200	11,040	100	104	2,000
144,000	42,940	100	104	4,300
360,000	106,730	110	130	9,000
1,440,000	414,060	250	143	30,800
2,880,000	784,460	350	160	57,000

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

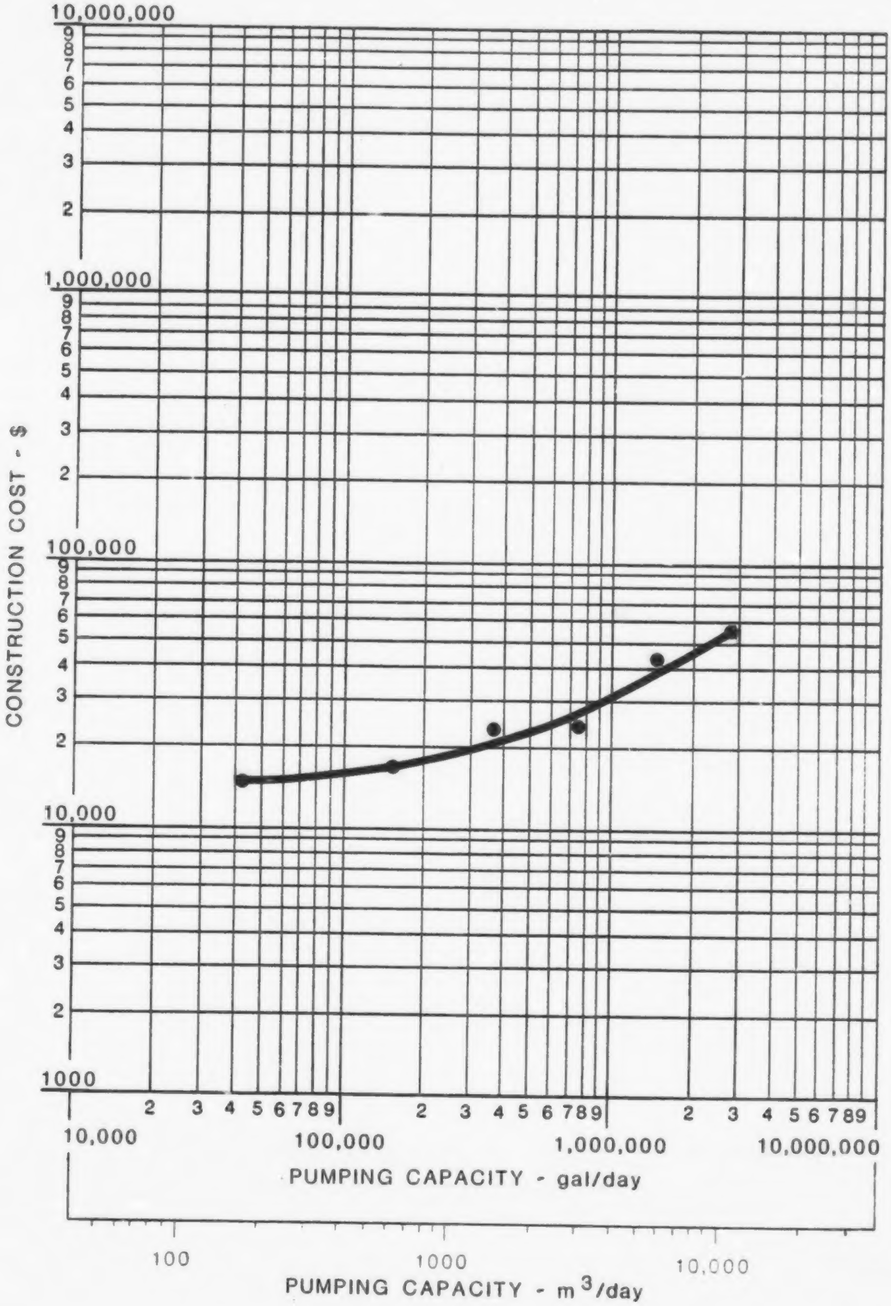


Figure 154. **Construction cost for package high service pumping stations.**

8 30

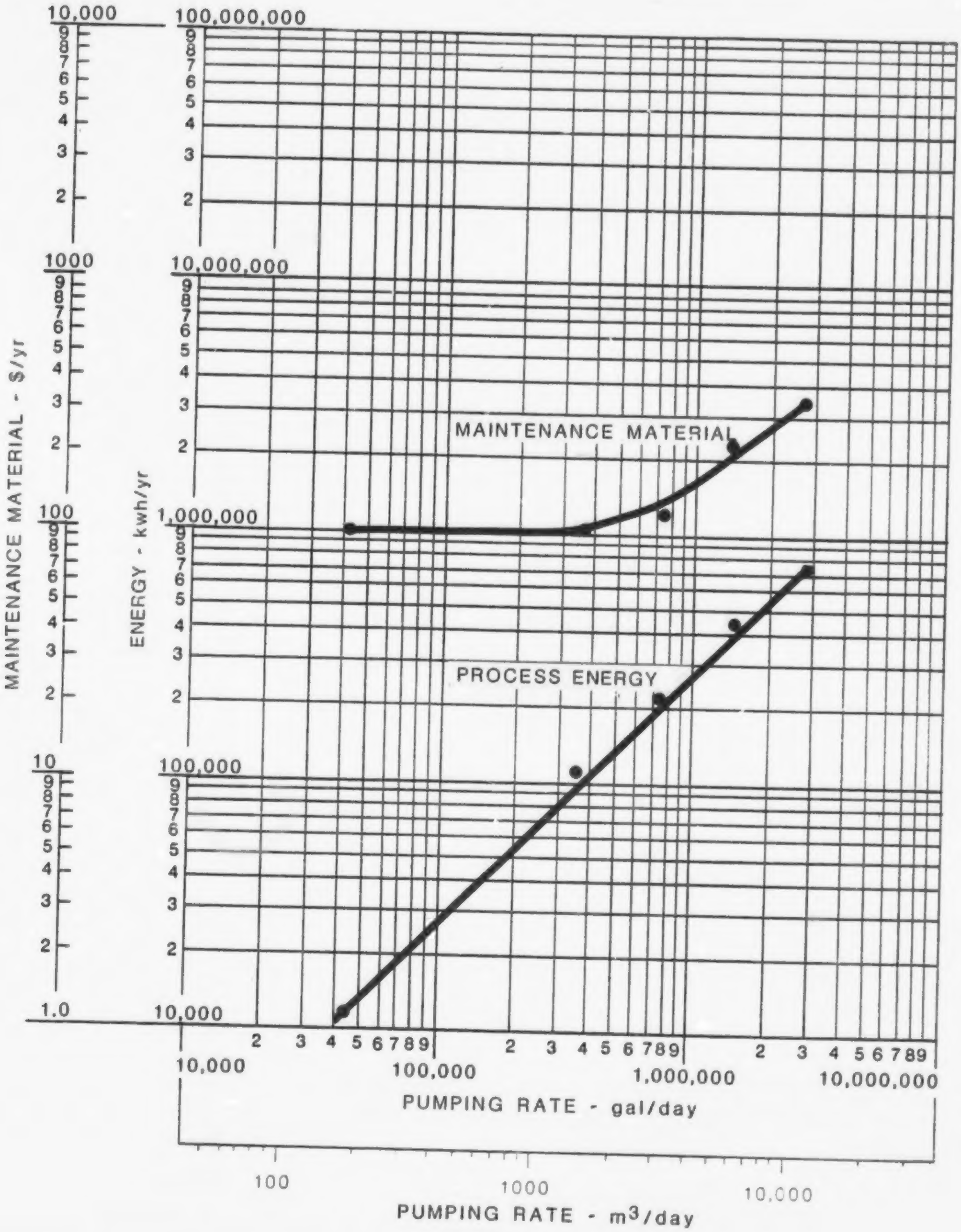


Figure 155. **Operation and maintenance requirements for package high service pumping stations - process energy and maintenance material.**

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30A

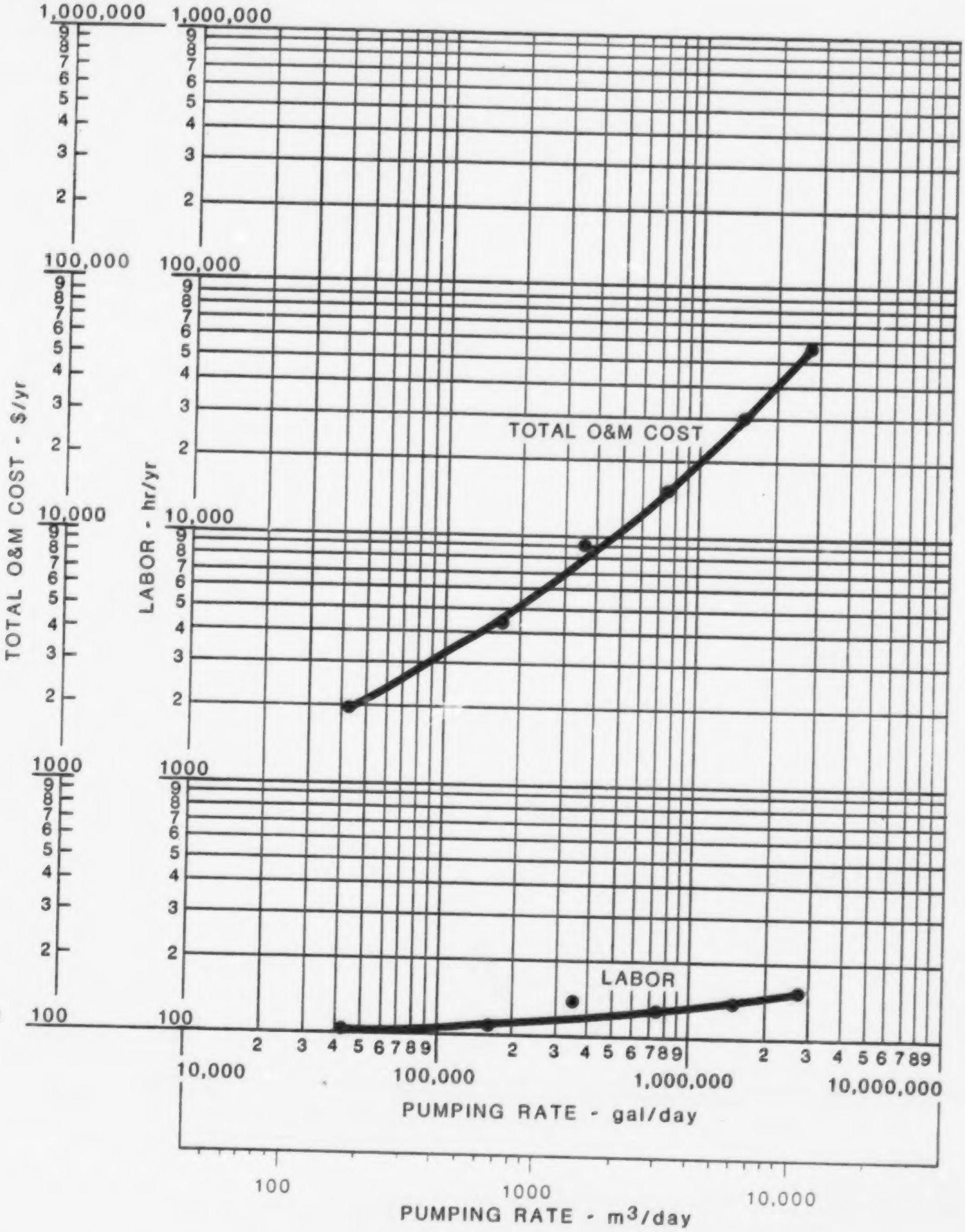

Figure 156. **Operation and maintenance requirements for package high service pumping stations - labor and total O&M cost.**

ESB
30B

FILTER MEDIA

Introduction

Package filtration plants and package complete treatment plants are usually furnished with either rapid sand, dual media or mixed media filtration materials and the costs presented in this report for these processes include an initial charge of media. Occasionally, however, media is replaced with the same media type, or a different media type. The costs in this section are intended to be used in such situations, and should not be added to the construction cost of package filtration plants or package complete treatment plants, which already include an initial media charge. Package plants using rapid sand are operated at filtration rates of 4.88 $m^3/m^2/h$ (2 gpm/sq ft) or less, while dual and mixed media are used for filtration rates of 9.76-12.2 $m^3/m^2/h$ (4-5 gpm/sq ft).

Where rapid sand media is used, pretreatment is generally extensive including coagulation, flocculation, and sedimentation, thus minimizing the suspended solids loading to the filters. Dual media and mixed media are capable of accepting greater suspended solids loadings than rapid sand, and often are used in systems providing minimal pretreatment, such as contact basins or high rate tube settling clarifiers. Where raw water is extremely low in suspended solids and largely free of bacterial contamination, dual or mixed media filtration preceeded by rapid mix or short detention flocculation basins may be permissible. For removal of iron and manganese from well waters, direct filtration may be applicable to any of the three different filtration media, depending upon the concentrations of iron and manganese in the raw water.

Impact of Raw Water Quality on Treatment Cost

As with all filtration systems, raw water quality influences treatment costs. Filtration rates, especially in a direct filtration application, are directly related to applied turbidity loadings. As raw water turbidities increase, greater coagulant dosages are required, decreasing allowable filtration rates to provide satisfactory performance. The combination of higher coagulant dosages and lower filtration rates increases the cost of the product water. For iron and manganese removal applications, increased concentrations require increased oxidant dosage, and a reduction in filtration rate.

Construction Costs

Costs are presented in Table 161 for rapid sand media using 76.2 cm (30 in) of silica sand, dual media using 50.8 cm (20 in) of anthracite coal and 25.4 cm (10 in) of silica sand and mixed media using 41.9 cm (16.5 in) of anthracite coal, 22.9 cm (9 in) of silica sand and 11.43 cm (4.5 in) of garnet sand all supported by a 30.5 cm (12 in) layer of graded supporting silica gravel.

The materials are shipped to the job site in 22.7 or 45.4 kg (50 or 100 lb) bags. The costs include labor to install the filter media. Costs presented elsewhere for package complete treatment plants, package pressure filtration plants, and package gravity filtration plants include mixed media at the costs shown in Table 161 and Figure 157.

TABLE 161. CONSTRUCTION COST SUMMARY FOR FILTER MEDIA

Filter Media, sq ft	Rapid Sand	Dual Media (coal-sand)	Mixed Media (coal-sand-garnet)
2	$ 300	$ 500	$ 1,000
10	1,100	1,700	3,300
20	1,900	2,700	5,200
40	3,300	4,900	8,400
80	5,700	8,300	11,100
160	10,100	14,700	19,800
350	$21,700	$31,600	$40,000

Note: Costs include installation of filter media.

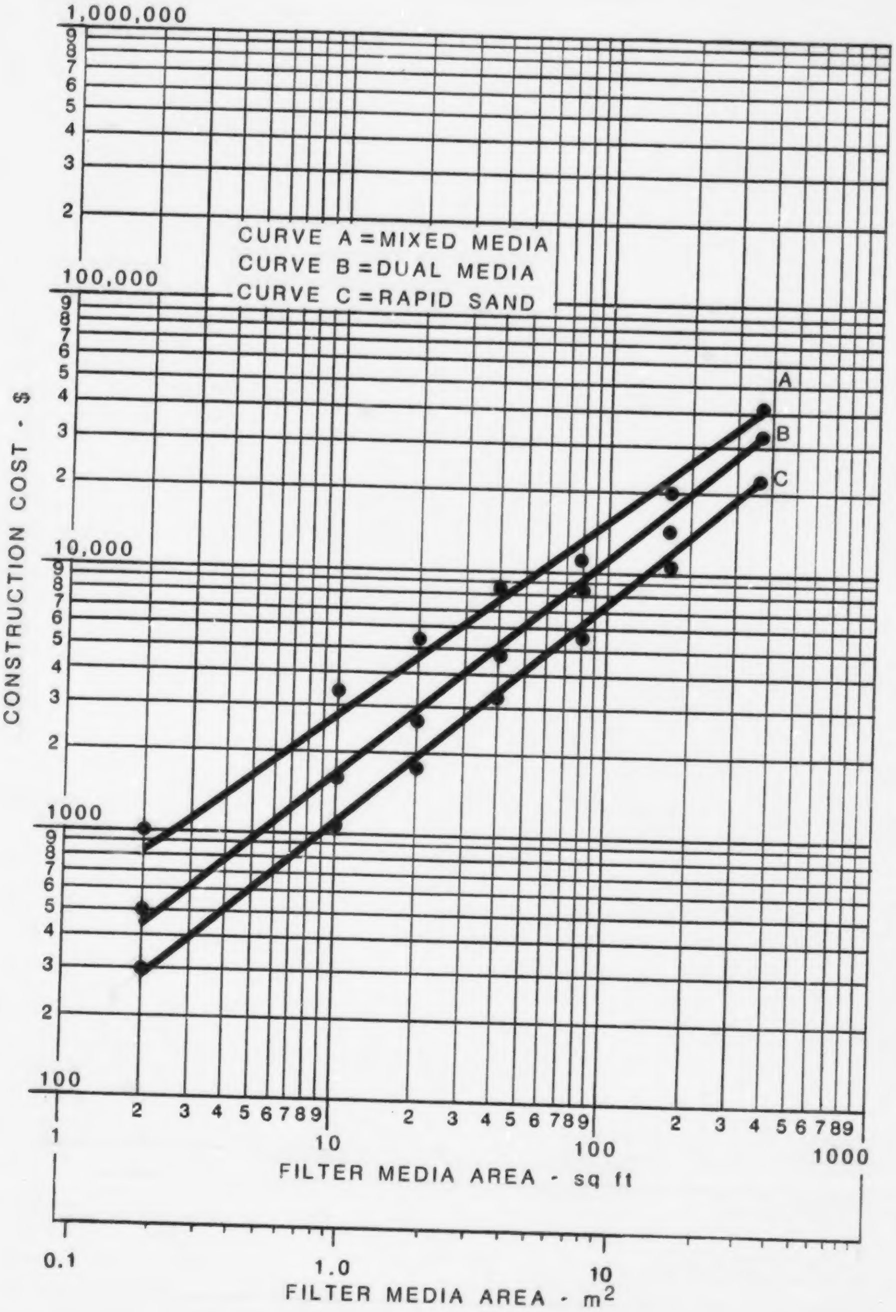

Figure 157. Construction cost for filter media.

12

PACKAGE FLOCCULATOR/CLARIFIER

Introduction

Package flocculator/clarifiers are often used in small water treatment systems to provide pretreatment prior to filtration. The majority use the solids contact or sludge blanket process of clarification. Typical applications are for turbidity and color removal, or for lime softening, and the flocculator/clarifier should be followed by filtration.

In a typical installation, coagulant is added to the raw water pipeline ahead of the flocculator/clarifier; this accomplishes some mixing within the pipeline. After the water enters the flocculator/clarifier, mixing and flocculation are provided by a slow moving mechanical agitator. Impurities are removed by adsorption and entrapment in the sludge blanket as the water passes upward to collection launders. Most units perform best at constant flows but can operate satisfactorily with narrow variations in flow.

Impact of Raw Water Quality on Treatment Cost

Raw water quality has an impact on both capital and operating cost. As raw water turbidity or color concentrations increase, longer detention times and lower clarification overflow rates are necessary, which increases capital cost. To compensate for colder waters, clarification must be assisted by polyelectrolyte coagulant aids, thereby increasing the operating cost per unit of capacity. Additionally, for very cold supplies, units are generally down rated in capacity, thereby increasing capital costs for a given treatment facility.

Construction Costs

Construction costs were developed for package flocculator/clarifiers based upon the conceptual designs presented in Table 162. The housing area shown in this table is for the flocculator/clarifier only, and does not include housing for the filters which customarily follow the flocculator/clarifier. The units are constructed of factory fabricated steel tankage and are shipped virtually completely assembled to the plant site. The tanks are rectangular in shape and include: flocculator drive and agitator; sludge blowoff valves and controls; influent distribution trough and effluent collection launders; and all internal piping and baffles.

TABLE 162. CONCEPTUAL DESIGNS FOR PACKAGE FLOCCULATOR/CLARIFIER

Settling Surface Area, sq ft	Number	Basin Dimensions, LxWxH, ft	Rise Rate, gpd/sq ft	Housing LxWxH	Housing sq ft
70	1	10x8x10.5	1,030	18x14x14	250
140	1	20x8x10.5	1,540	28x14x14	390
250	1	25x11x10.5	1,730	33x17x14	560
370	1	34x12x10.5	1,560	42x18x14	760
740	2	34x12x10.5	1,560	42x34x14	1,430

The costs are for a completely housed installation, and also include influent, effluent, and sludge piping within the battery limits of the installation. The costs exclude raw water and finished water pumping and coagulant feed equipment. Construction costs are summarized in Table 163 and are also shown in Figure 158.

TABLE 163. CONSTRUCTION COST SUMMARY FOR PACKAGE FLOCCULATOR/CLARIFIER

Cost Category	Settling Surface Area, sq ft 70	140	250	370	740
Excavation and Sitework	$ 2,700	$ 4,200	$ 5,400	$ 7,300	$ 12,200
Manufactured Equipment	31,300	44,800	58,200	67,500	128,800
Concrete	4,100	6,100	8,600	10,900	19,100
Labor, Installation	6,500	8,300	9,600	10,400	20,000
Pipe and Valves	900	2,900	4,400	5,600	8,400
Electrical, Instrumentation	2,600	2,900	3,100	3,500	5,300
Housing	19,000	25,400	31,400	38,000	51,500
Subtotal	67,100	94,600	120,700	143,200	245,300
Design Contingencies	10,100	14,200	18,100	21,500	36,800
Total	$77,200	$108,800	$138,800	$164,700	$282,100

Operation and Maintenance Requirements and Costs

Process energy is required to operate the flocculator drive motor and electrically actuated automatic valves. Requirements were developed based on year round, 24 hour per day operation. Building energy consumption is based upon 209.8 kwh/m^2/yr (19.5 kwh/sq ft/yr) for heating, ventilating and lighting. This value assumes building lights are in use three hours each day.

Maintenance materials are for replacement of components such as flocculator drives and motors which wear out or break down during normal operations. Chemical costs are not included in maintenance materials, but are discussed in the following section.

Labor requirements cover both maintenance and operation. The majority of the labor is required for routine operations. The operator is required on a daily basis to check the process and mechanical operation of the flocculator/clarifier to insure that the water is being clarified properly. Adjustment of chemical dosage may be required to compensate for raw water quality changes. Labor requirements for chemical preparation are not included, as they are included in the cost data for chemical feed systems. Other labor involves performing routine testing and general maintenance and housekeeping of the facilities.

Operation and maintenance requirements and costs are summarized in Table 164 and presented in Figures 159 and 160 for plants with surface settling areas between 6.5 and 68.7 m^2 (70 and 740 sq ft).

TABLE 164. OPERATION AND MAINTENANCE SUMMARY FOR PACKAGE FLOCCULATOR/CLARIFIER

Settling Surface Area, sq ft	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
70	4,900	3,300	8,200	250	130	2,300
140	7,600	3,300	10,900	300	195	3,200
250	10,900	5,000	15,900	375	208	3,800
370	14,800	6,700	21,500	450	260	4,800
740	27,900	13,300	41,200	850	338	7,500

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

Typical Chemical Requirements and Costs

In clarification processes, coagulants such as alum, ferrous sulfate and ferric sulfate are used either separately or in combination with polyelectrolyte coagulant aids to remove turbidity and color. Dosages are variable and are influenced by such raw water characteristics as the amount and type of turbidity, presence of organic materials measured as color, pH, water temperature, and the overall chemical composition of the water supply.

Typical coagulant dosages are difficult to establish. In general, package flocculator/clarifiers perform most efficiently at alum dosages ranging between 10 and 30 mg/L. Settling is improved by addition of coagulant aids at a ratio of alum to polymer of 100:1 to 50:1.

Table 165 presents estimated chemical costs for package flocculator/clarifiers assuming an alum dosage of 20 mg/L and a polyelectrolyte dosage of 0.2 mg/L. Chemical costs used in Table 165 are $0.33/kg ($0.15/lb) for alum and $6.61/kg ($3.00/lb) for polymer.

TABLE 165. TYPICAL CHEMICAL COSTS FOR PACKAGE FLOCCULATOR/CLARIFIER

Plant Flow, gpd	Alum		Polymer		Total Chemical Cost, $/yr
	lb/yr	$/yr	lb/yr	$/yr	
72,000	4,380	660	44	120	780
216,000	13,130	1,970	131	390	2,360
432,000	26,260	3,940	263	780	4,700
576,000	35,030	5,250	350	1,050	6,300
1,152,000	70,060	10,510	700	2,100	12,600

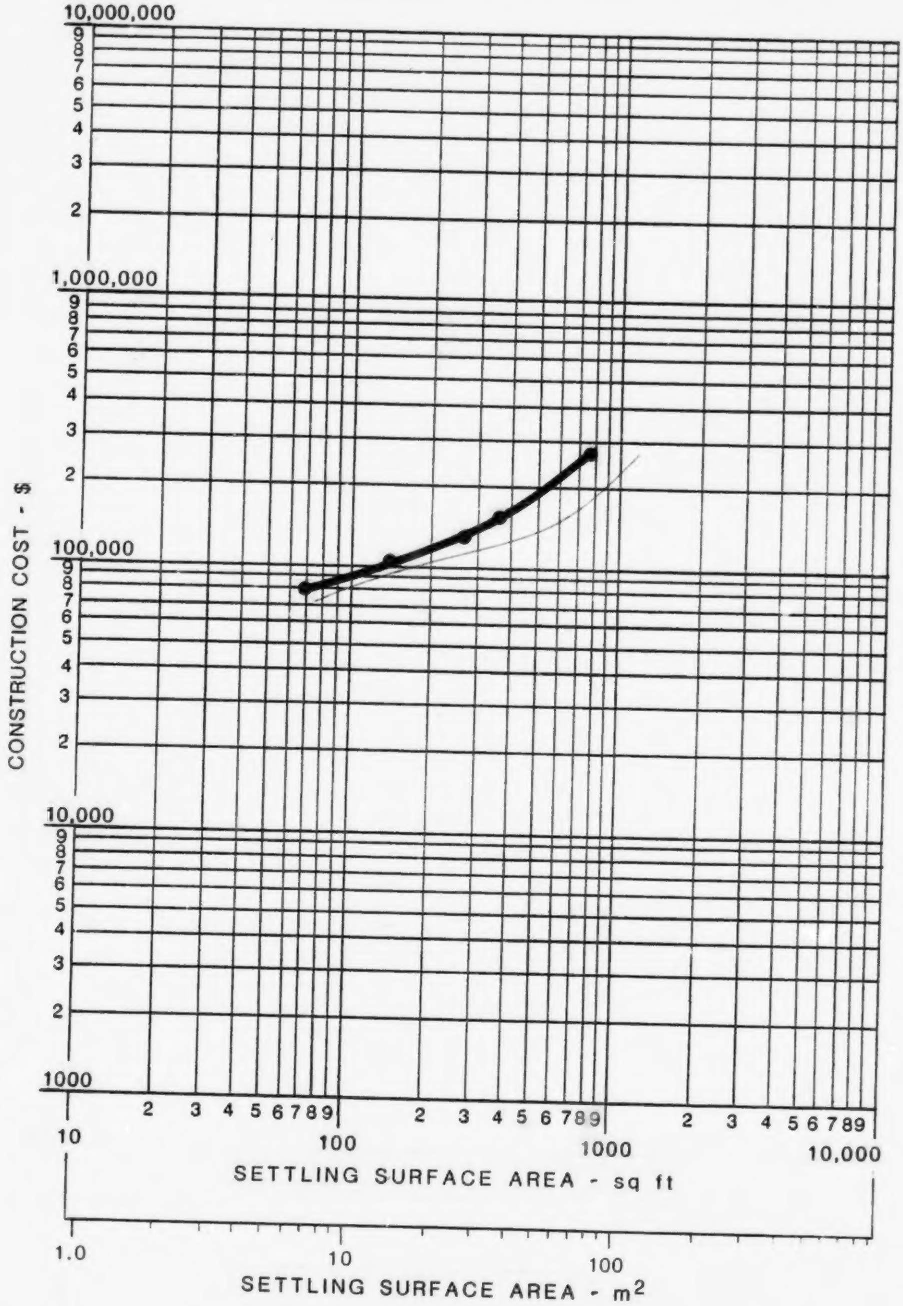

Figure 158. Construction cost for package flocculator/clarifier.

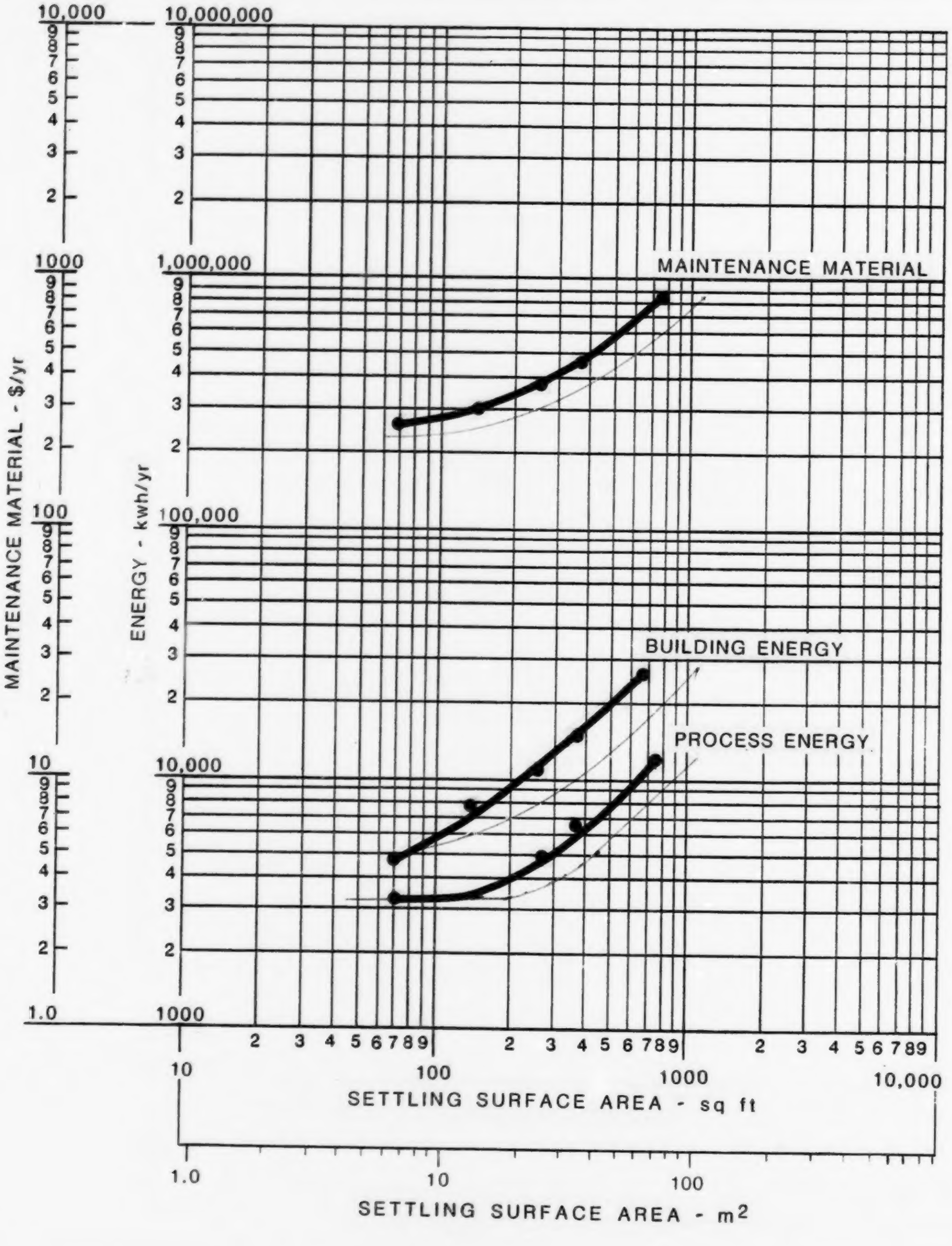

Figure 159. **Operation and maintenance requirements for package flocculator/clarifier - building energy, process energy, and maintenance material.**

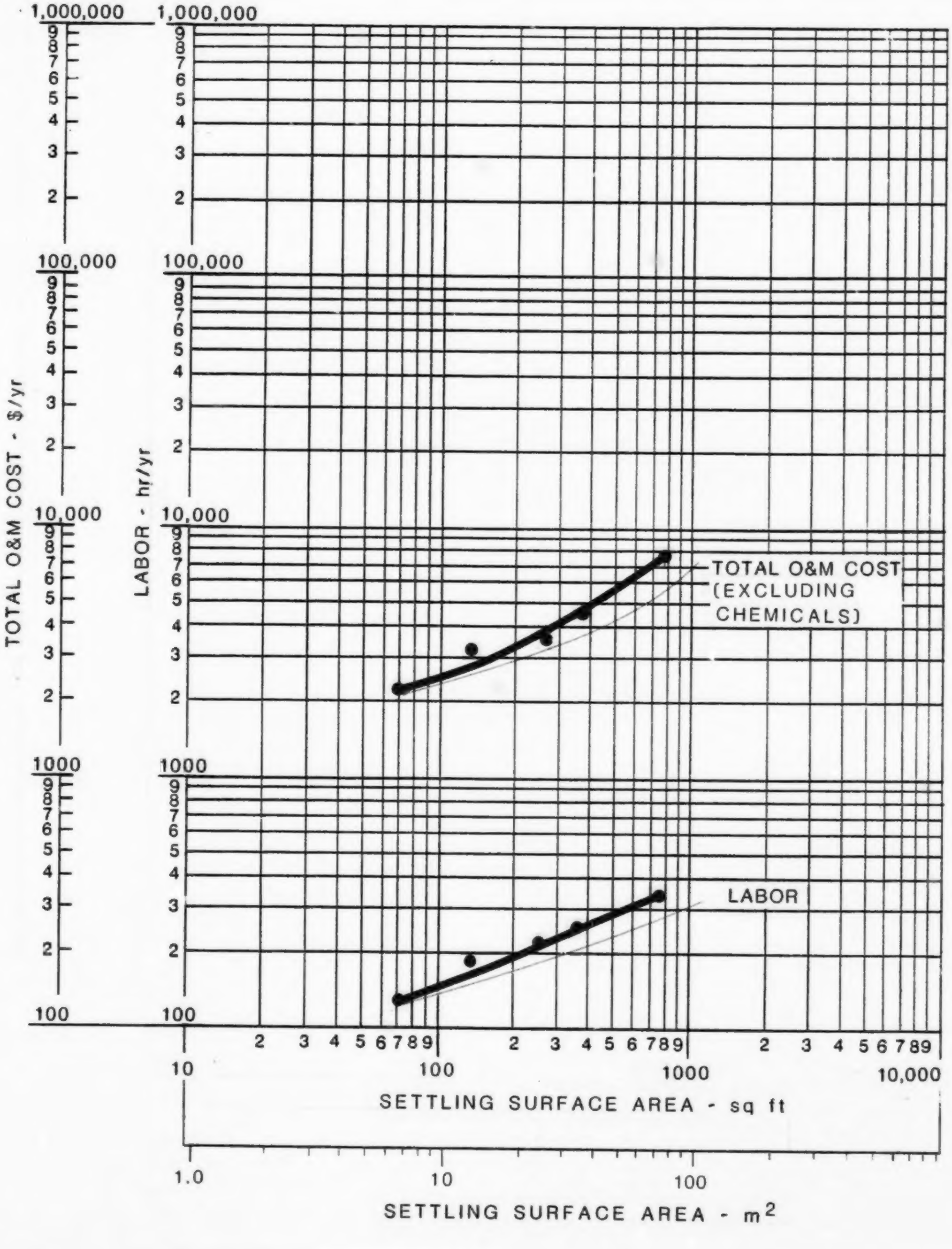

Figure 160. **Operation and maintenance requirements for package flocculator/clarifier - labor and total O&M cost.**

CONTACT BASINS - DIRECT FILTRATION APPLICATIONS

Introduction

Contact basins are often used for pretreatment ahead of gravity or pressure filters in direct filtration applications. Typically they are designed with 60 minutes of detention time, have no provisions for mechanical mixing, and are cleaned manually by periodically draining and flushing. Their purpose is to remove coarse suspended solids, provide time for completion of coagulation reactions and provide for prechlorination contact time.

Construction Costs

Conceptual design information which was used in the development of construction costs is shown in Table 166. The basins are factory fabricated using 0.64 cm (0.25 in) thick steel plate, and are equipped with inlet, outlet, and drain piping, access ladder and are finish painted. Circular tanks are used to provide up to 45,400 L (12,000 gal) of contact basin volume, while rectangular steel tanks are used for the larger basins. The tanks are supported on a concrete base slab and are not housed. Construction costs are presented in Table 167 and illustrated in Figure 161.

Operation and Maintenance Requirements and Costs

Contact basins have no power requirements, as there is no pumping or mechanical mixing, and the units are not housed.

Maintenance material requirements are minimal and include occasional touch-up painting to control corrosion on the tank and to replace worn components on drain valves.

Labor requirements are for periodic draining and flushing of the tank to remove accumulations of debris and for general housekeeping of the equipment.

TABLE 166. CONCEPTUAL DESIGNS FOR CONTACT BASINS - DIRECT FILTRATION APPLICATIONS

Basin Volume, gal	Plant Flow Rate, gpd*	Basin Dimensions, ft				Number of Basins
		Depth	Width	Length	Diameter	
1,200	28,800	10	-	-	4.5	1
6,000	144,000	10	-	-	10	1
12,000	288,000	10	-	-	10	2
21,000	504,000	10	10	28	-	1
30,000	720,000	10	10	20	-	2
42,000	1,008,000	10	12	23	-	2

Note: *Basins provide 60 minute detention at indicated flow rate.

TABLE 167. CONSTRUCTION COST SUMMARY FOR CONTACT BASINS - DIRECT FILTRATION APPLICATIONS

Cost Category	Basin Volume, gal 1,200	6,000	12,000	21,000	30,000	43,000
Excavation and Sitework	$ 200	$ 300	$ 300	$ 900	$ 1,300	$ 1,800
Manufactured Equipment	1,600	4,900	9,900	30,300	43,300	60,600
Concrete	200	500	1,100	1,500	2,200	2,700
Labor, Installation	600	1,000	1,700	3,200	4,800	8,500
Pipe and Valves	300	800	1,800	2,500	3,300	4,600
Subtotal	2,900	7,500	14,800	38,400	54,900	78,200
Design Contingencies	400	1,100	2,200	5,800	8,200	11,700
Total	$3,300	$8,600	$17,000	$44,200	$63,100	$89,900

Note: *Basins provide 60 minute contact time at indicated flow rate.

Operation and maintenance requirements are summarized in Table 168 and illustrated in Figure 162.

TABLE 168. OPERATION AND MAINTENANCE SUMMARY FOR CONTACT BASINS - DIRECT FILTRATION APPLICATIONS

Basin Volume, gal	Plant Capacity, gpd	Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
1,200	20	100	10	200
6,000	100	150	20	400
12,000	200	250	35	600
21,000	350	350	50	900
30,000	500	600	60	1,300
42,000	700	750	70	1,500

Note: Total cost is based on $11.00/hour of labor.

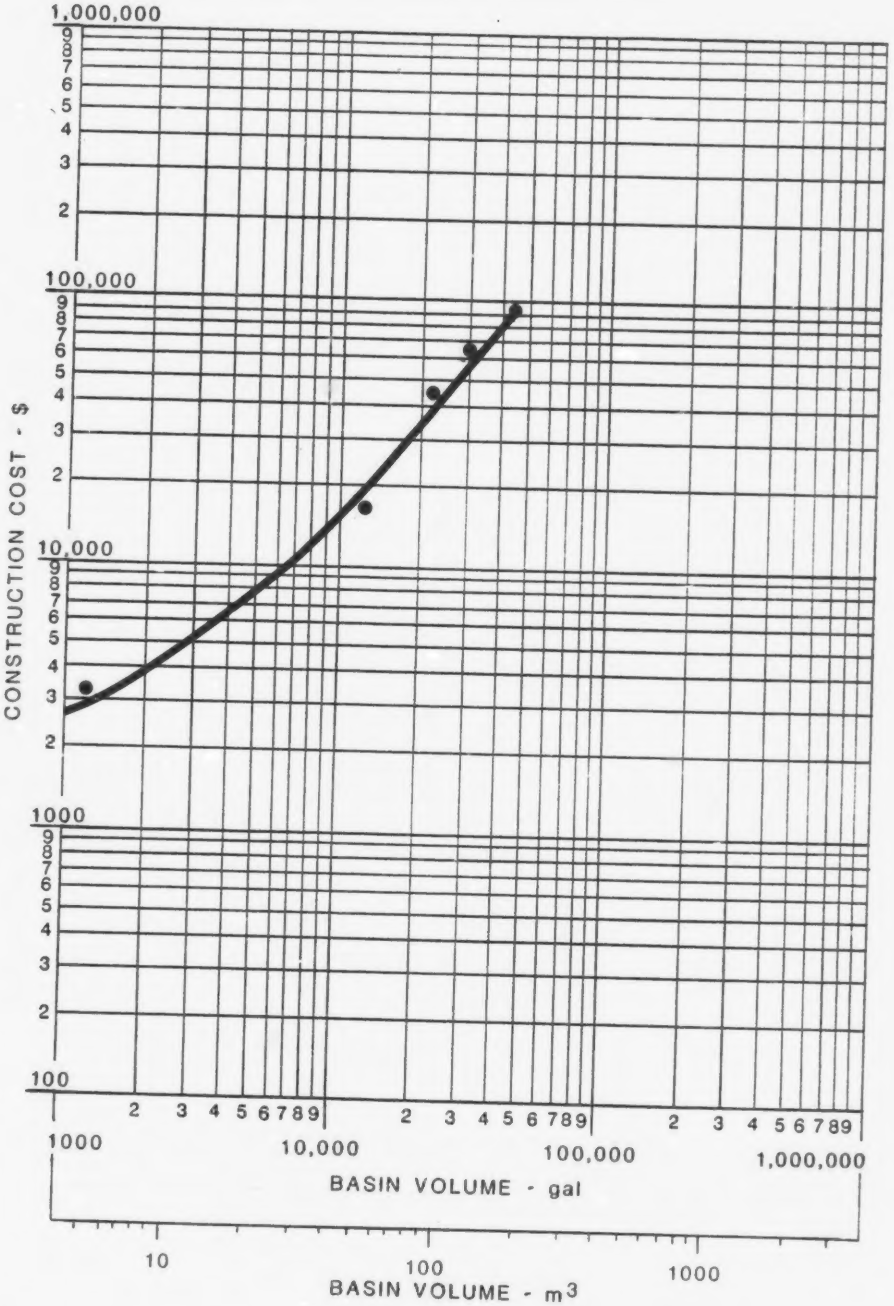

Figure 161. Construction cost for contact basins used in direct filtration applications.

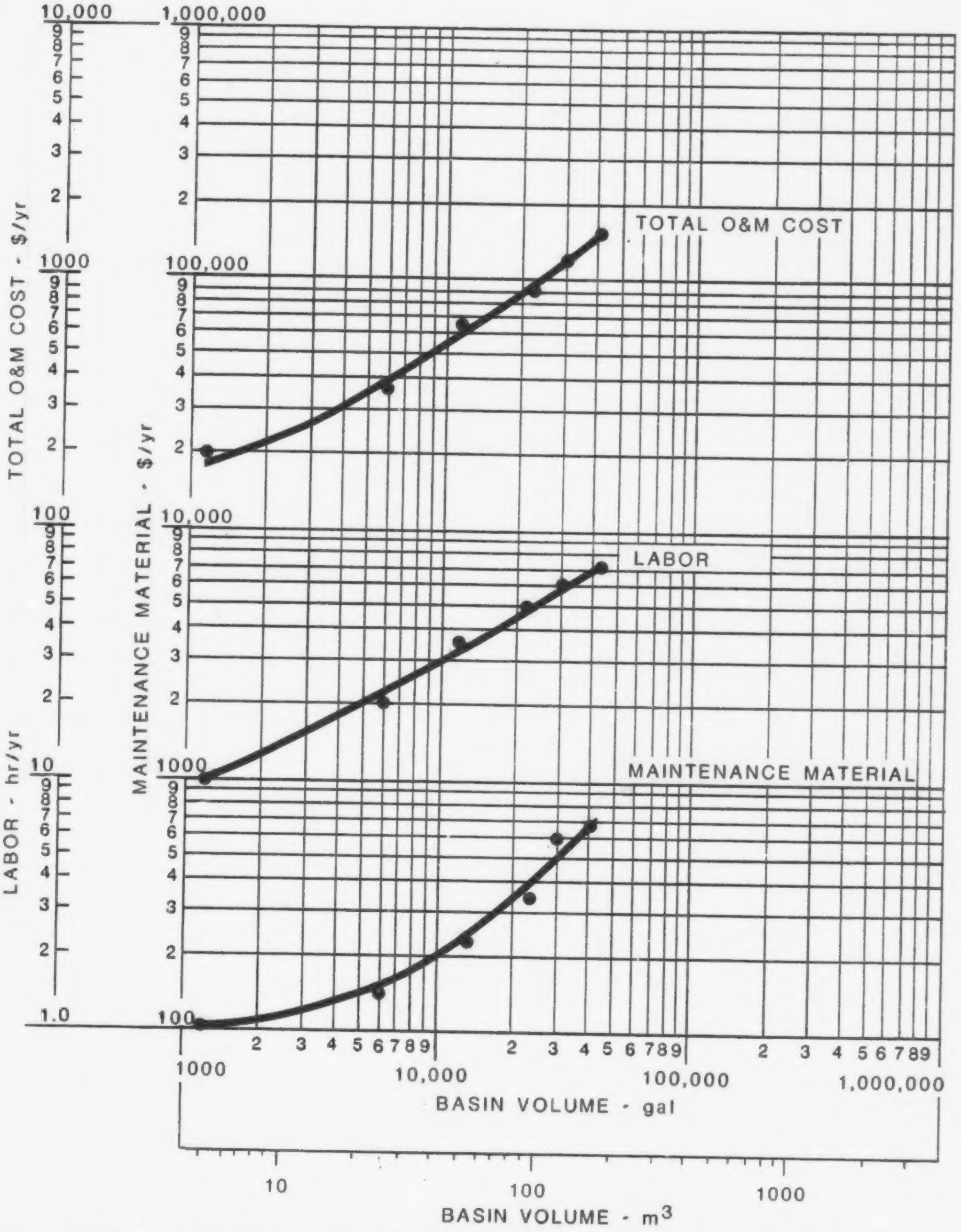

Figure 162. **Operation and maintenance requirements for contact basins used in direct filtration applications - maintenance material, labor, and total O&M cost.**

ULTRAVIOLET LIGHT DISINFECTION

Introduction

Ultraviolet (UV) light may be used to disinfect or even sterilize water. The method of microbiological destruction is UV light penetration of the microbial cell wall followed by a virtually instantaneous reaction of the UV light with genetic portions of the cellular contents. An advantage of disinfection with UV light is that no potentially hazardous reaction products are formed. However, no residual disinfection capability is provided, and this is a disadvantage.

UV light disinfection reactors are usually tubular, containing tubular low-pressure mercury lamps in watertight quartz sleeves. The UV light which is produced is invisible to the eye, although the lamps do produce about 10 percent visible light, a pale, blue-violet glow. This visible light does not have disinfection capability. Single reactors are usually available at flow rates as low as 0.063 L/s (1 gpm) to as high as 31.55 L/s (500 gpm).

Several variables may be cited as design criteria, but all are related back to the primary objective of the process, i.e., destruction of microorganisms. To achieve this objective, a great majority of the microorganisms of public health concern must be struck by a lethal photon (a discrete UV light particle), and the photon must react with the genetic contents. The two prominent factors which mitigate against a photon striking a microorganism and reacting with the inter-cellular genetic portions are: (1) absorption of photons by water and its impurities, and (2) the discrete nature of photons and the distance between microorganisms. Thus, the variables of concern in meeting required microorganism destruction levels are: (1) dose - the number of photons released in a given time period; (2) detention time - the amount of time a volume of water is subject to exposure to photons; (3) thickness of water layer - the greatest distance a microorganism may be from the UV light source. The rate of destruction of a specific microorganism is a direct function of the dose and detention time and is an inverse function of layer thickness.

Some microorgansims require greater UV dosages to obtain the desired level of destruction. Of particular importance are Giardia cysts, which require higher dosages than can be provided by some UV units. Where Giardia are a potential problem, use of UV for disinfection should be carefully evaluated.

Unfortunately, there are no uniform national standards for UV light disinfection. Equipment manufacturers customarily rate their equipment in terms of dose and flow rate. Dose is usually reported as energy per unit area in microwatt-seconds per square centimeter. Between different equipment models and manufacturers, dose can range from as low as 16,000 to as high as 70,000 uw-sec/cm^2. Along with this wide range in dose, different equipment will provide widely varying detention time and water layer thickness. Thus, care must be exercised when selecting UV light disinfection equipment; required levels of disinfection must be achieved, but energy must not be wasted by needless overdosing. Pilot scale testing is recommended.

Because there is no uniform procedure used by manufacturers to rate their equipment, overall plant capacity in gallons/day has been used as the most applicable design parameter in the subsequent cost discussion and presentation.

Impact of Raw Water Quality on Treatment Cost

Transmission of UV energy through the water is essential for adequate disinfection. Decreasing transmissivity impacts both capital and operation costs. A water with low UV energy transmission characteristics will require a higher dosage, a thinner water layer, or longer detention time in the disinfection equipment.

A low-turbidity water is essential to the use of UV disinfection, and decreasing turbidity is a principal factor in increasing the clarity to UV light. However, many substances can interfere with UV light transmissivity. For example, iron and chlorine will reduce UV clarity; chlorine in the range 5-15 mg/L will significantly reduce UV transmissivity. Any tint to the water, especially toward the color red, generally means a low UV transmissivity. Additionally, some dissolved organics can interfere with UV light transmissivity.

Most equipment manufacturers will test water samples for UV transmissivity. Prior to selection of this treatment technique, water samples should be tested to determine whether UV light disinfection is applicable, what additional processes, if any, would be required to use UV light disinfection, and design criteria for the UV equipment.

Construction Costs

Construction costs are based on a two-unit facility, with each UV unit providing half the rated capacity. The costs include piping to and from the units, the UV light disinfection reactor, a UV light intensity meter, and housing. The UV light disinfection reactors are furnished by the manufacturer as assembled modules which require only a power source and connecting piping. The cost of the UV light reactors was based on the average cost of several manufacturers' recommended unit for a particular flow. It was assumed that the housing provided was a portion of a larger building, as the units do not require a great deal of space. Table 169 and Figure 163 presents the construction costs for flow rates from 0.25 to 44.2 L/s (4 gpm to 700 gpm).

Operation and Maintenance Requirements and Costs

Operation and maintenance costs were developed, based on the two-unit facility and manufacturer's recommended operating conditions for dosage and flow capacity. Continuous 24-hour operation was assumed. Building energy use is for heating, ventilating, and lighting, while process energy use is primarily for the mercury lamps. Maintenance materials requirements include annual replacement of all lamps and seals. Labor requirements include daily monitoring and annual cleaning and lamp replacement. Operation and maintenance requirements and costs are summarized in Table 170 and illustrated in Figures 164 and 165.

TABLE 169. CONSTRUCTION COST SUMMARY FOR ULTRAVIOLET LIGHT DISINFECTION

Cost Category	Plant Capacity, gpd					
	5,760	14,400	57,600	288,000	576,000	1,008,000
Excavation and Sitework	$ 100	$ 100	$ 100	$ 100	$ 100	$ 100
Manufactured Equipment	1,000	1,800	4,200	11,800	18,700	26,400
Concrete	700	900	1,100	1,800	2,300	2,900
Labor, Installation	600	700	800	1,500	1,900	2,300
Pipe and Valves	200	300	400	2,400	3,800	4,200
Electrical, Instrumentation	600	600	600	600	700	700
Housing	5,600	7,200	8,400	12,600	15,400	18,000
Subtotal	8,800	11,600	15,600	30,800	42,900	54,600
Design Contingencies	1,300	1,700	2,300	4,600	6,400	8,200
Total	$10,100	$13,300	$17,900	$35,400	$49,300	$62,800

Note: Housing requirements from smallest plant capacity to largest are 70, 90, 110, 180, 230, and 290 sq ft. All buildings have a 10 ft height.

TABLE 170. OPERATION AND MAINTENANCE SUMMARY FOR ULTRAVIOLET LIGHT DISINFECTION

Average Plant Flow Rate, gpd	Energy, kwh/yr			Maintenance Material, $/yr	Labor, hr/yr	Total Cost, $/yr
	Building	Process	Total			
5,760	1,000	900	1,900	230	68	1,100
14,400	1,300	1,100	2,400	250	68	1,200
57,600	1,600	3,900	5,500	750	70	1,900
288,000	2,600	15,100	17,700	2,300	76	4,400
576,000	3,400	26,500	29,900	4,000	80	7,000
1,008,000	4,200	46,300	50,500	6,800	84	11,300

Note: Total cost is based on $0.07/kwh of electrical energy and $11.00/hour of labor.

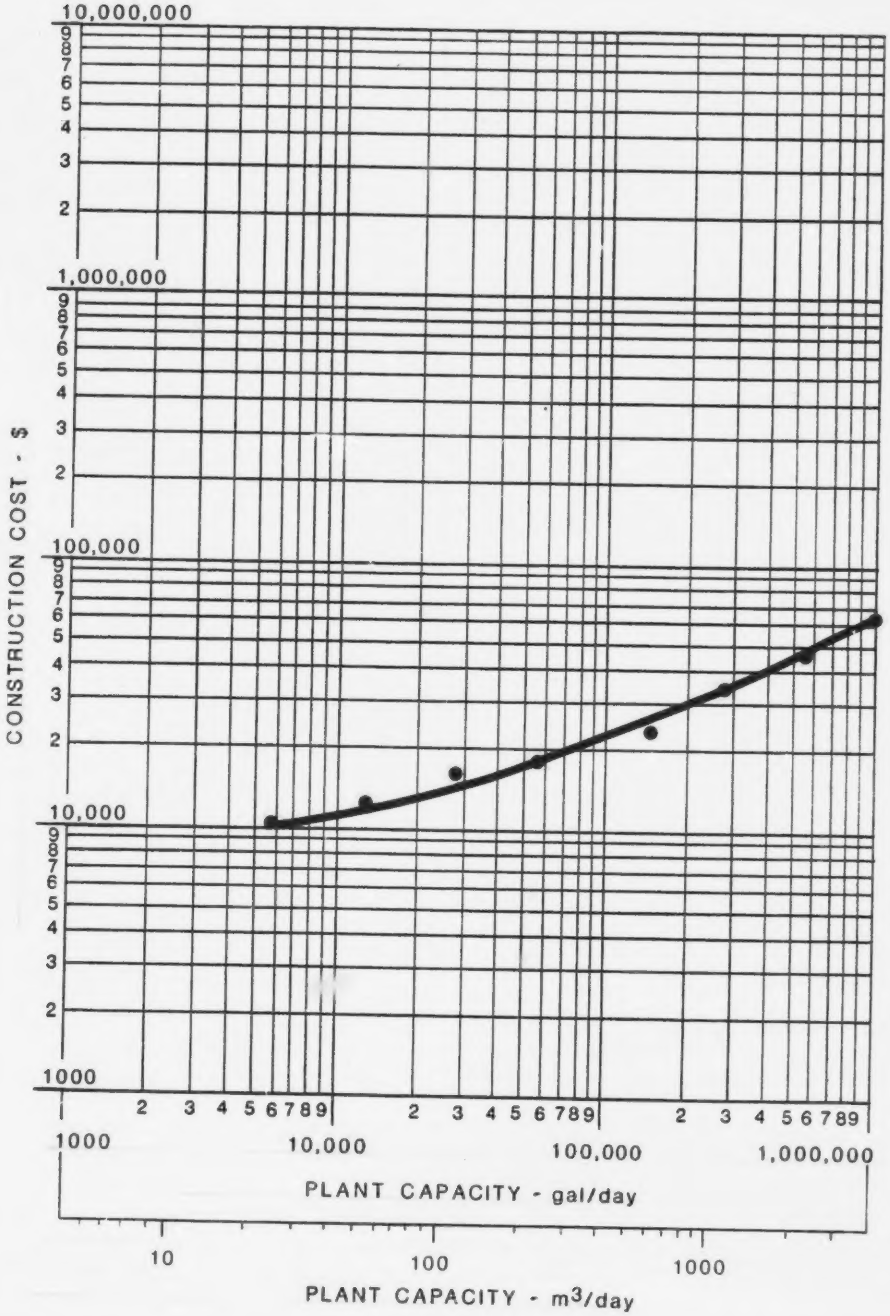

Figure 163. Construction cost for ultraviolet light disinfection.

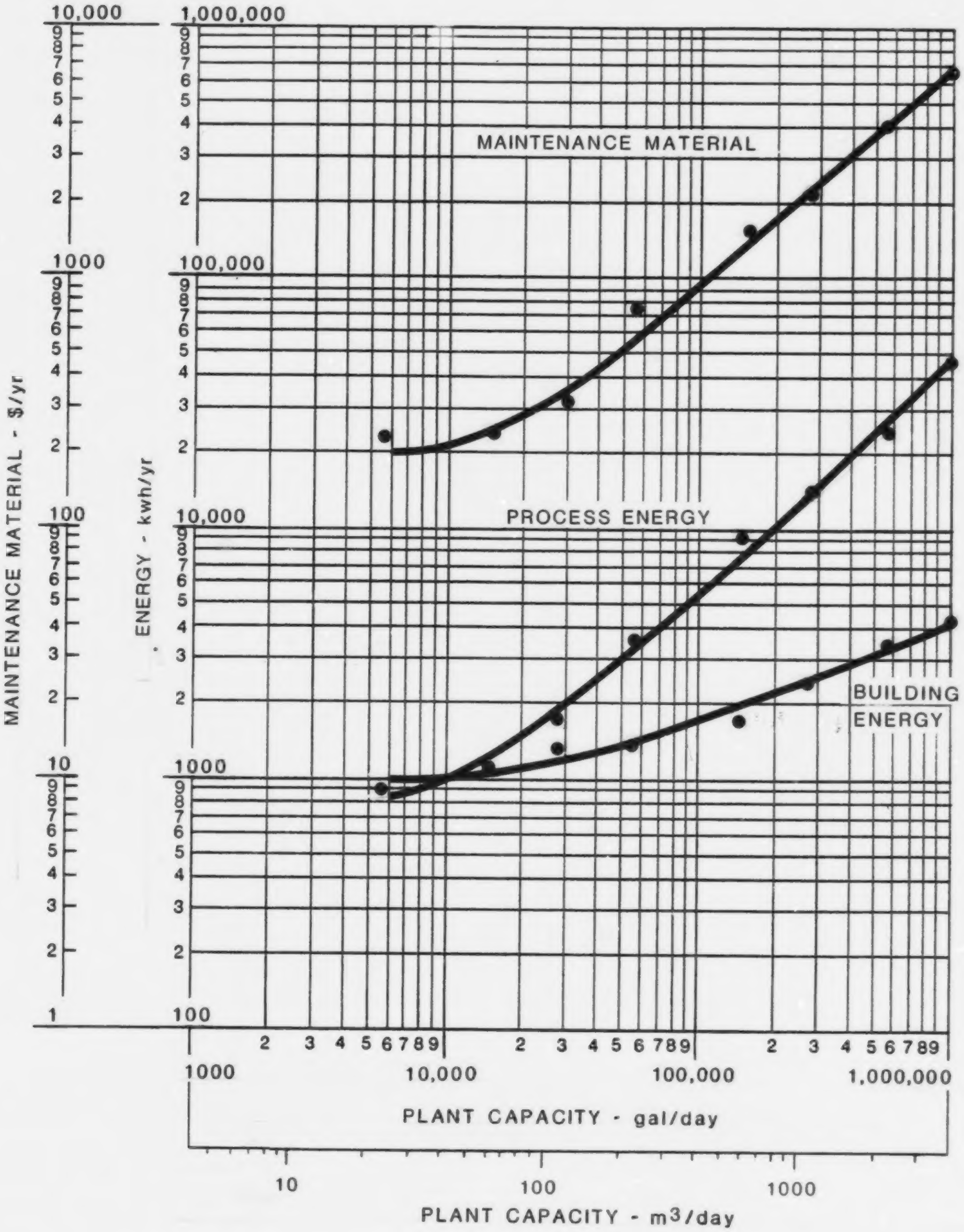

Figure 164. **Operation and maintenance requirements for ultraviolet light disinfection - building energy, process energy, and maintenance material.**

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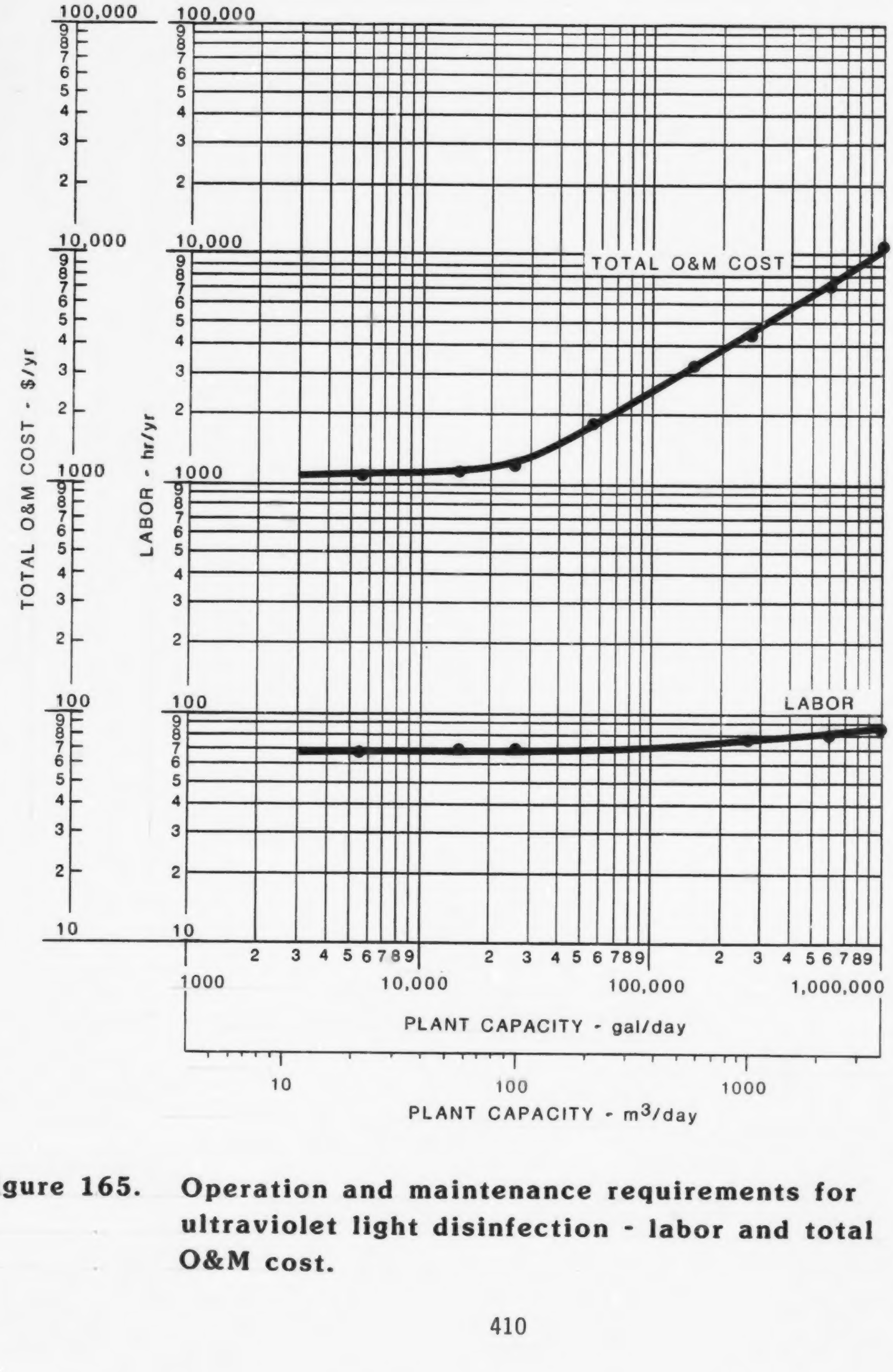

Figure 165. **Operation and maintenance requirements for ultraviolet light disinfection - labor and total O&M cost.**

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CLEARWELL STORAGE

Construction Costs

Product filtered water is commonly stored in a clearwell at the plant site which serves as a supplement to distribution system storage before high-service pumping. In many cases, filter backwash pumps also draw from the clearwell, eliminating the need for a separate sump. Clearwell storage may be either below ground in reinforced concrete structures, or above ground in steel tanks. Conceptual designs for below and above-ground level clearwells are shown in Table 171.

TABLE 171. CONCEPTUAL DESIGNS FOR CLEARWELL STORAGE

Below-Ground Concrete Clearwells				Ground-Level Steel Clearwells		
	Size, ft				Size, ft	
Capacity, gal	Length	Width	Depth	Capacity, gal	Diameter	Depth
5,000	8	8	10	1,000	5.7	5
10,000	11	11	12	5,000	8.5	12
50,000	18	18	20	10,000	12	12
100,000	26	26	20	25,000	15	20
500,000	58	58	20	100,000	23.5	32
				500,000	52	32
				1,000,000	74	32

Construction costs are shown in Table 172 for below-ground reinforced concrete clearwells and in Table 173 for ground-level steel clearwells. Costs for ground-level clearwells are based on field erected welded steel tanks designed to meet AWWA D100 for 18.93 m^3 (5,000 gal) and more, and on shop fabricated welded steel tanks for the 3.79 m^3 (1,000 gal) tank. Steel tanks are painted inside and out and are installed on a concrete ring wall with oiled sand cushion. Cathodic protection is included for tanks with capacities of 94.63 m^3 (25,000 gal) and larger. A typical ground-level storage reservoir is shown in Figure 166. Figure 167 presents the construction costs for both types of clearwells.

TABLE 172. CONSTRUCTION COST SUMMARY FOR BELOW-GROUND CONCRETE CLEARWELL STORAGE

Cost Category	Clearwell Capacity, gal 5,000	10,000	50,000	100,000	500,000
Excavation and Sitework	$ 3,300	$ 5,700	$16,500	$ 25,300	$ 75,400
Concrete	9,800	16,500	37,000	64,000	216,400
Steel	300	400	500	500	600
Electrical, Instrumentation	2,600	2,600	2,600	2,600	2,600
Subtotal	16,000	25,200	56,600	92,400	295,000
Design Contingencies	2,400	3,800	8,500	13,900	44,300
Total	$18,400	$29,000	$65,100	$106,300	$299,300

TABLE 173. CONSTRUCTION COST SUMMARY FOR GROUND-LEVEL STEEL CLEARWELLS

Cost Category	Clearwell Capacity, gal 1,000	5,000	10,000	25,000	100,000	500,000	1,000,000
Excavation and Sitework	$ 100	$ 100	$ 100	$ 100	$ 200	$ 400	$ 500
Concrete	3,100	5,300	6,600	8,400	11,400	25,700	37,100
Steel Tank	3,000	4,900	12,600	26,600	52,300	121,200	191,000
Electrical, Instrumentation	2,600	2,600	2,600	2,600	2,600	2,600	2,600
Subtotal	8,800	12,900	21,900	37,700	66,500	149,900	231,200
Design Contingencies	1,300	1,900	3,300	5,700	10,000	22,500	34,700
Total	$10,100	$14,800	$25,200	$43,400	$76,500	$172,400	$265,900

Notes: 1. Oiled sand cost is included in concrete category.
2. Cathodic protection cost is included in the steel tank category.

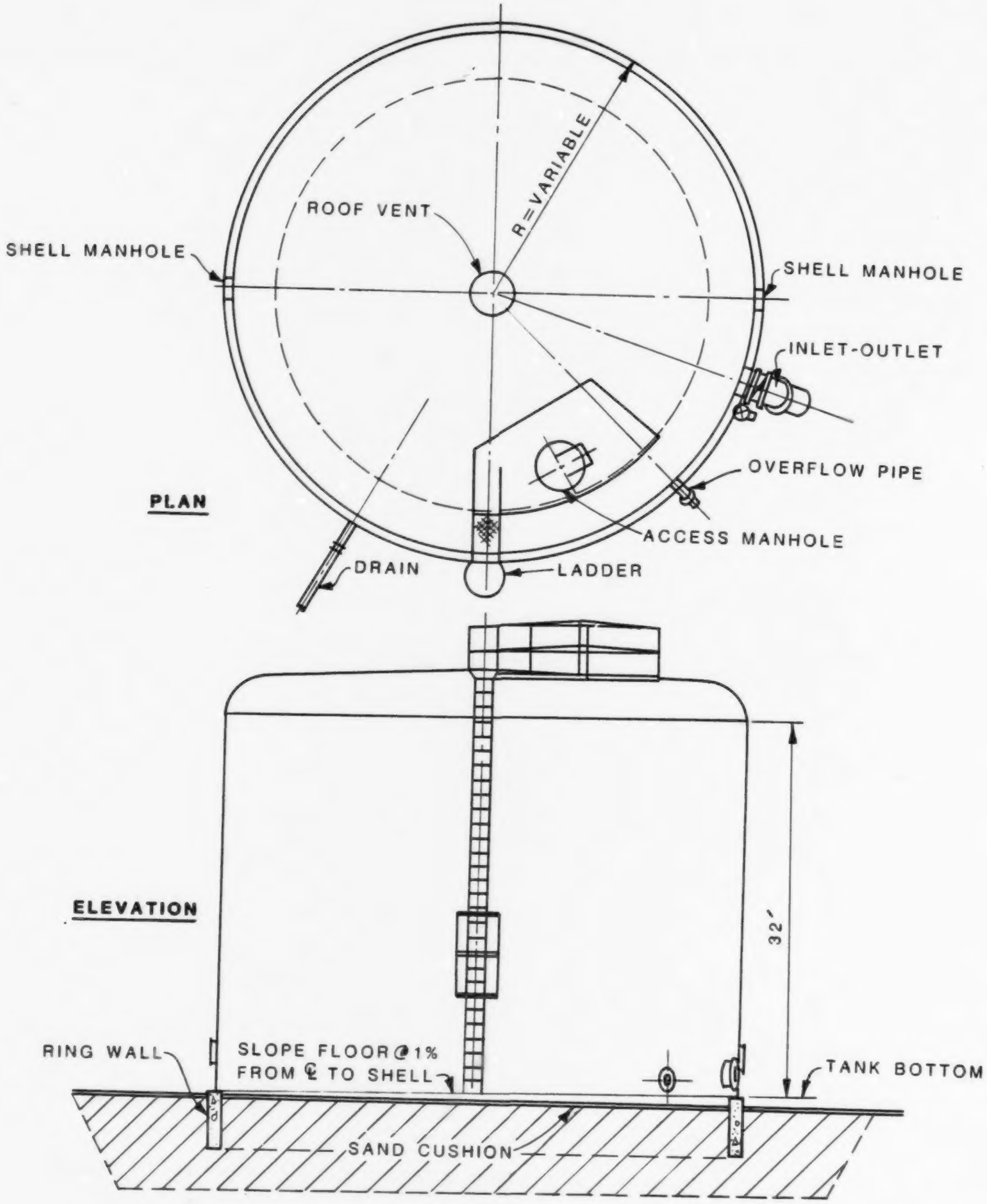
R=VARIABLE
ROOF VENT
SHELL MANHOLE
SHELL MANHOLE
INLET-OUTLET
OVERFLOW PIPE
PLAN
ACCESS MANHOLE
DRAIN
LADDER
ELEVATION
32'
RING WALL
SLOPE FLOOR @ 1%
FROM ℄ TO SHELL
TANK BOTTOM
SAND CUSHION

Figure 166. Typical ground-level steel clearwell.

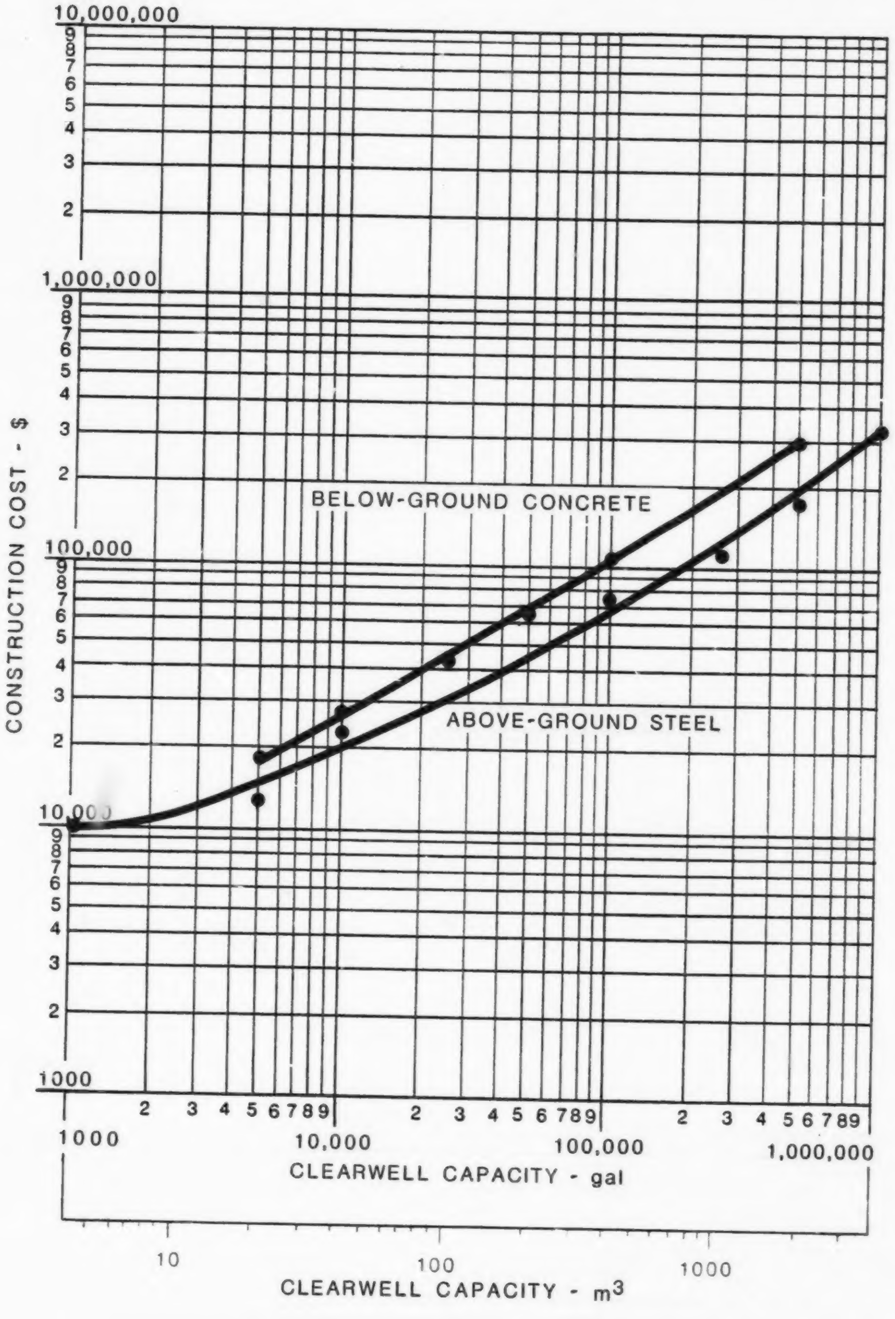

Figure 167. Construction cost for clearwell storage.

SECTION 6

POINT-OF-USE TREATMENT

INTRODUCTION

Point-of-use treatment, also referred to as decentralized treatment, is defined as treatment provided at the individual home. Conversely, centralized treatment is performed on a larger scale at a single location. Point-of-use treatment has several advantages over centralized treatment. These advantages include:

- Small capital investment relative to centralized treatment.
- A smaller volume of water treated, since only water used for drinking and food preparation is treated. A special tap is added at the kitchen sink to supply the treated flow.

However, there are also disadvantages of point-of-use treatment, including the following:

- High operation and maintenance costs.
- Potential difficulty of gaining access for treated water sample collection and equipment servicing.
- Potential for bacterial growth on the surface of media within the treatment units.
- Inability to allow process optimization, such as inability to adjust pH to optimum conditions.

Point-of-use treatment is used only for water utilized for drinking and food preparation. It is served from a separate tap, customarily located at the kitchen sink.

APPLICATIONS

The most applicable treatment techniques for point-of-use treatment are:

- Reverse osmosis
- Activated alumina
- Granular activated carbon
- Cation exchange
- Anion exchange

These techniques are all applicable to the removal of more than one of the contaminants included in the Interim Primary Drinking Water Regulations, as shown in Table 174. This capability should be considered in process selection if more than one contaminant must be removed.

LOCATION OF POINT-OF-USE TREATMENT DEVICES

Point-of-use treatment devices can be installed at either of two locations:

- Under the kitchen sink (or in the basement).
- In an underground meter box at the property line.

For both types of installations, the treatment units are identical. Faucet mounted devices which use granular activated carbon are also available. These devices have an extremely small volume of carbon relative to the point-of-use treatment equipment included in this report, and will not be discussed further.

Installation Under the Kitchen Sink

Installation under the kitchen sink is simpler and less expensive than the outdoor underground system. A connection to the cold water line is made under the sink and a shutoff valve is provided between the cold water line and the treatment device. A line from the treatment device then connects to a new faucet mounted on the sink. It is assumed that a hole must be drilled, with a carbide drill bit, through the sink for the new faucet. A system located in the basement would be directly under the kitchen and therefore very close to the sink. The pipe run to the sink will be longer yet the cost increase would be minimal. Typical under the sink installations are shown in Figures 168 and 169.

Installation at the Property Line

The second installation technique is to locate the treatment device at the property line in a plastic meter box; the top of the box is located at ground level. A typical installation is shown in Figure 170. The meter box has an opening in the cover which allows utility personnel to remove and replace the treatment units when regeneration is required. The treatment unit sits inside a vertical section of PVC pipe which is buried underground, and rests on a gravel base. A copper tube is tapped into the main house water supply line to supply water to the treatment unit. A shutoff valve is provided upstream of the treatment unit, and a sampling tap is provided downstream; both the shutoff valve and sampling tap are available for access at the meter box. A 1.3 cm (0.5 in) PVC pipeline is used to connect the treatment unit with the special tap located at the kitchen sink.

Advantages and Disadvantages

The advantage of under the sink installation is lower cost (usually) and protection from adverse weather conditions, particularly freezing. The

TABLE 174. PRIMARY DRINKING WATER REGULATION CONTAMINANTS REMOVED BY POINT-OF-USE TREATMENT

	Reverse Osmosis	Activated Alumina	Anion Exchange	Cation Exchange	Activated Carbon
Arsenic					
Pentavalent	X	X	X		
Barium	X			X	
Cadmium	X			X	
Chromium					
Trivalent	X			X	
Hexavalent	X		X		
Fluoride	X	X			
Lead	X			X	
Mercury					
Inorganic	X				X
Organic	X				X
Nitrate	X		X		
Selenium					
Quadravalent	X	X	X		
Hexavalent	X		X		
Silver	X			X	
Organics					X
Radioactivity					
Alpha Emitters					
Radium	X			X	
Uranium	X		X		
Beta Emitters	X				

Notes: 1. Removal efficiencies are a function of the raw water contaminant concentration, as well as the overall raw water quality.

2. Radioactive substances behave the same as nonradioactive substances relative to removal. Each radioisotope must be considered individually, and can not be treated as a general classification such as an alpha, beta or gamma emitter. This table is intended to present only guidance on removal of radioactivity.

disadvantage is potential difficulty of access for sample collection and replacement of exhausted treatment devices.

Location at the property line insures right-of-access for servicing and sample collection. However, in locations where winter freezing occurs, such outdoor location would probably not be practical. In addition, initial cost is usually higher, particularly when the treated water line to the house must pass under extensively landscaped areas. Reverse osmosis point-of-use treatment could not be located at the property line, because there is no readily available sewer connection for discharge of brine. One state, Arizona, requires that point-of-use treatment devices be located at the property line.

EQUIPMENT AVAILABILITY

Equipment is currently available for reverse osmosis, cation exchange, and granular activated carbon point-of-use treatment. Availability of this equipment is evidence of a relatively large market. For activated alumina, equipment is available on a limited basis, while anion exchange point-of-use devices are not commonly marketed. However, equipment for anion exchange is virtually identical to that used for cation exchange, except for the resin. The lack of readily available equipment for activated alumina and anion exchange point-of-use treatment is indicative of a small market.

Equipment costs presented in the subsequent sections are based upon appropriately sized equipment for installation under the sink or at the property line. In general, larger sizes are available, but installation as point-of-use treatment would be difficult.

MANAGEMENT OF POINT-OF-USE TREATMENT DEVICES

Responsibility for installation and maintenance of point-of-use treatment devices for removal of Primary Drinking Water Regulation contaminants rests with the utility, due to the legal responsibilities of the utility to supply a water which meets the Regulations. Maintenance of point-of-use devices which are installed by the homeowner for removal of Secondary Drinking Water Regulation contaminants would be the responsibility of the individual homeowner.

The responsibilities of the utility in managing point-of-use treatment devices include:

- Purchasing treatment units.
- Initial installation of treatment units.
- Routine sampling to determine if product water quality conforms to the Regulations.
- Maintenance of the treatment devices, including replacement of exhausted components and correction of any leaks in the system. This maintenance includes regeneration and/or replacement, as necessary, of

ion exchange resins, granular activated carbon, activated alumina, and reverse osmosis membranes. Regeneration and/or replacement may be conducted by the utility, or may be contracted by the utility to a local firm specializing in such work.

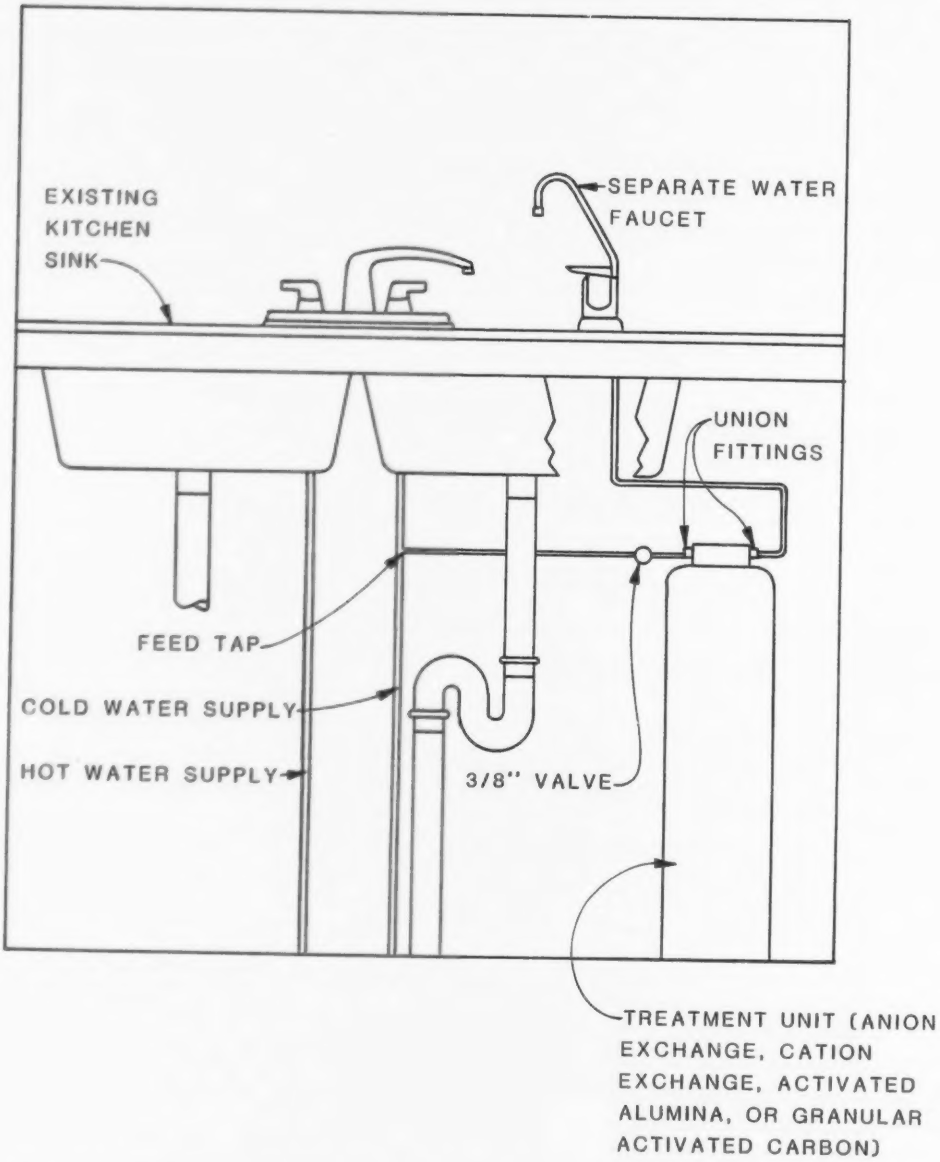
EXISTING KITCHEN SINK
SEPARATE WATER FAUCET
UNION FITTINGS
FEED TAP
COLD WATER SUPPLY
HOT WATER SUPPLY
3/8" VALVE
TREATMENT UNIT (ANION EXCHANGE, CATION EXCHANGE, ACTIVATED ALUMINA, OR GRANULAR ACTIVATED CARBON)

Figure 168. **Typical under sink installation of a point-of-use system for anion or cation exchange, activated alumina, or granular activated carbon.**

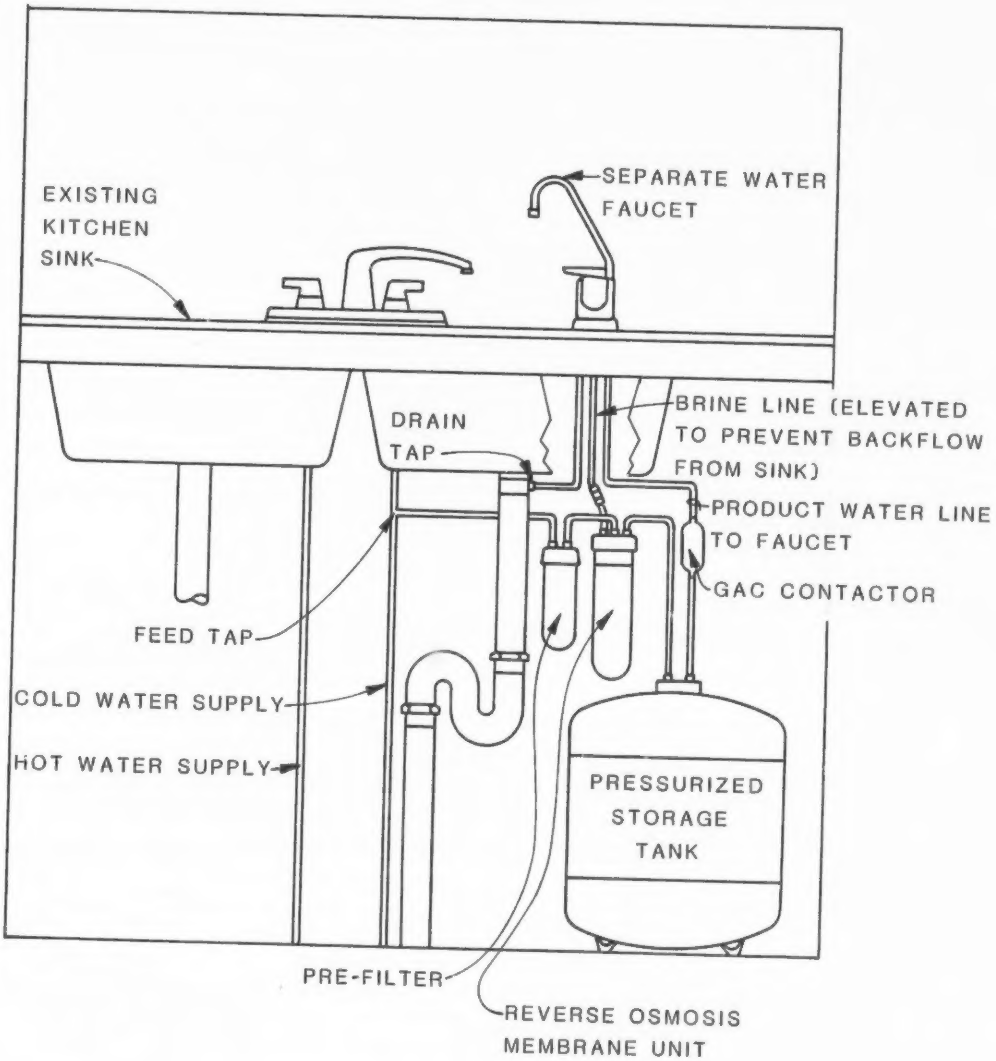
SEPARATE WATER FAUCET
EXISTING KITCHEN SINK
BRINE LINE (ELEVATED TO PREVENT BACKFLOW FROM SINK)
DRAIN TAP
PRODUCT WATER LINE TO FAUCET
GAC CONTACTOR
FEED TAP
COLD WATER SUPPLY
HOT WATER SUPPLY
PRESSURIZED STORAGE TANK
PRE-FILTER
REVERSE OSMOSIS MEMBRANE UNIT

Figure 169. **Typical under sink installation of a reverse osmosis point-of-use treatment system.**

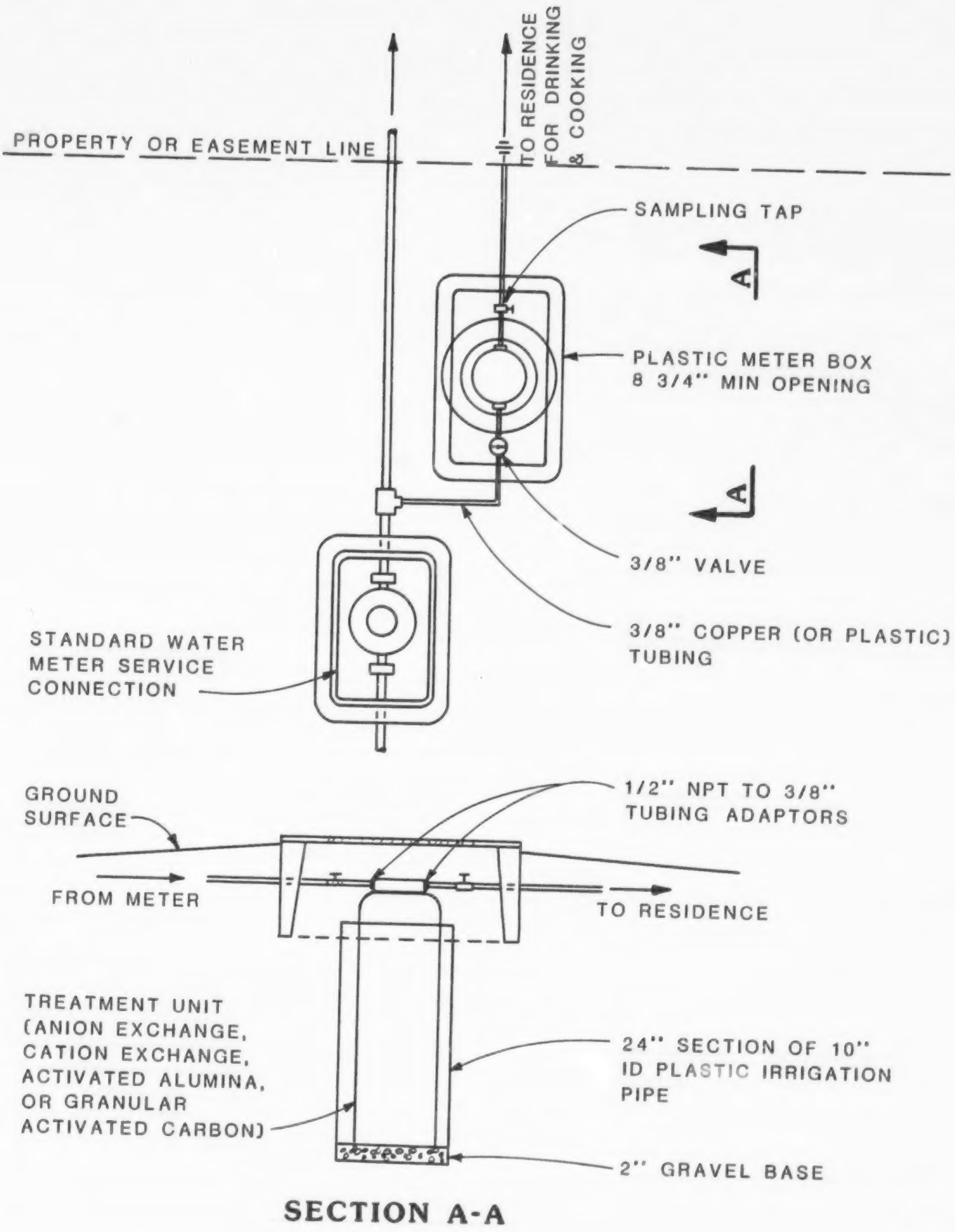
TO RESIDENCE FOR DRINKING & COOKING
PROPERTY OR EASEMENT LINE
SAMPLING TAP
A
PLASTIC METER BOX 8 3/4" MIN OPENING
A
3/8" VALVE
3/8" COPPER (OR PLASTIC) TUBING
STANDARD WATER METER SERVICE CONNECTION
GROUND SURFACE
1/2" NPT TO 3/8" TUBING ADAPTORS
FROM METER
TO RESIDENCE
TREATMENT UNIT (ANION EXCHANGE, CATION EXCHANGE, ACTIVATED ALUMINA, OR GRANULAR ACTIVATED CARBON)
24" SECTION OF 10" ID PLASTIC IRRIGATION PIPE
2" GRAVEL BASE
SECTION A-A

Figure 170. Typical point-of-use treatment device installed underground at the property line.

REVERSE OSMOSIS POINT-OF-USE TREATMENT

Introduction

Reverse osmosis units can be used for point-of-use removal of a variety of inorganic contaminants, including arsenic, barium, cadmium, chromium, fluoride, lead, mercury, nitrate, selenium, and silver; reverse osmosis units can also be used to remove radioactivity. Most reverse osmosis units which are currently in use in homes have been installed by the homeowner to remove total dissolved solids to improve the taste of their drinking water. Typically, point-of-use reverse osmosis treatment systems are designed to be installed under a kitchen sink and to provide water through a separate tap or faucet mounted on the sink. The treated water is used only for drinking or cooking, which prolongs the life of the reverse osmosis system. Property line installations are generally not feasible, because a brine/waste line is necessary.

Construction Costs

Construction costs for point-of-use reverse osmosis systems are presented in Table 175 for installations located under the kitchen sink. The cost for manufactured equipment includes a reverse osmosis membrane unit, a pre-filter, a pressure reservoir, a small GAC post-contactor, a special faucet and all required tubing, fittings and adaptors. In virtually all commercially available equipment, cellulose acetate membranes are utilized. The disadvantage of using thin film composite membranes is the necessity to use GAC pre-treatment for chlorine removal. This GAC must be maintained in an active state, for any penetration of chlorine will result in membrane deterioration.

TABLE 175. CONSTRUCTION COST SUMMARY FOR REVERSE OSMOSIS POINT-OF-USE TREATMENT

Cost Category	Construction Cost, $
Manufactured Equipment	$330
Labor, Installation	50
Subtotal	380
Contingency	60
Total	$440

Note: For an additional cost of $40, a water meter can be installed after the filter to record the amount of water treated and to help the utility estimate membrane life.

The 5 micron pre-filter removes particles such as sediment or dirt and is necessary to protect the reverse osmosis membrane. The reverse osmosis membrane unit has a capacity of producing up to 19 L (5 gal) of water per day. A connection to the sink drain line is required for disposal of waste brine. A pressure reservoir stores treated water in a plastic lined steel chamber with a 12 L (3.2 gal) storage capacity; the reservoir is pressurized by air behind a rubber diaphragm. The GAC contactor is located in the line between the storage reservoir and the faucet and is 5 cm (2 in) in diameter by 18 cm (7 in) long; the GAC contactor removes chlorine and taste and odor causing compounds which may have passed through the reverse osmosis membrane.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements for point-of-use reverse osmosis systems are only for labor and material costs. No electricity is required since the water pressure typically delivered to the home (40 psi or greater) is sufficient for operation of the reverse osmosis unit. The operation and maintenance requirements are separated into four cost categories: sampling/testing, pre-filter and GAC contactor replacement, reverse osmosis membrane replacement, and repairs.

A summary of operation and maintenance requirements is shown in Table 176. A range of requirements is shown for each cost category, so that the level of sampling frequency of pre-filter and GAC contactor replacement, interval of reverse osmosis membrane replacement, and level of repairs can be selected by the user of this cost information.

Labor requirements are for collecting water quality samples for testing reverse osmosis system performance, for replacing the pre-filter and GAC contactor, for replacing the reverse osmosis membrane module, and for infrequent repairs on the system. Sampling/testing requirements are for the contaminant(s) the system is designed to remove; when the contaminant level rises above the MCL, it is time for replacement of the reverse osmosis membrane. The pre-filter and GAC contactor typically have a shorter useful life than a reverse osmosis membrane and are replaced more frequently.

Maintenance material requirements are for sampling, filter and GAC replacement, reverse osmosis and membrane replacement, and any other repair components required. Material requirements for sampling are for the costs of laboratory analyses required to test the level of the contaminant(s) being removed. Material requirements for pre-filter and GAC contactor replacement are the costs for new pre-filter cartridges and a new GAC contactor. The material cost for the reverse osmosis unit is for replacement of the reverse osmosis membrane module which fits inside the membrane unit. Material requirements for repairs are for tubing or fittings.

TABLE 176. OPERATION AND MAINTENANCE SUMMARY FOR REVERSE OSMOSIS POINT-OF-USE TREATMENT

Cost Category	Labor, hr/yr	Materials, $/yr	Total Cost, $/yr Specific Condition	Total Cost, $/yr Mid-Range Condition
Sampling/Testing				
Frequency				
2/yr	2	40	62	
4/yr	4	80	124	$124
6/yr	6	120	186	
Pre-Filter and GAC Contactor Replacement				
Frequency				
1/yr	1	20	31	
2/yr	2	40	62	62
Reverse Osmosis Membrane Replacement				
Interval				
1 yr	1	75	86	
2 yr	0.5	38	44	44
3 yr	0.3	25	28	
Repairs				
Low	1	10	21	
Average	2	20	42	42
High	3	30	63	
			Total Cost for Mid-Range Condition =	$272/yr

Notes: 1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.

ACTIVATED ALUMINA POINT-OF-USE TREATMENT

Introduction

Activated alumina is used for defluoridation of water supplies, although it can also be used to remove pentavalent arsenic and quadravalent selenium, as shown in Table 174. Installation of the activated alumina treatment unit may be either under the kitchen sink or at the property line, as shown in Figures 168 and 170.

Construction Costs

Construction costs for point-of-use defluoridation by activated alumina filtration are presented in Table 177 both for installations located under the sink (or in the basement) and for installations located underground at the property line. For either location, the activated alumina filter cannister is the same, a 14.2 L (0.5 cu ft) fiberglass cylinder which is 18 cm diameter by 56 cm high (7 in diameter by 22 in high).

For installation at the property line, the cost estimate for the PVC piping from the meter box to the house ($20 for pipe and $40 for installation labor) would be highly variable depending on location. For homes which are close to the curb and which have only a grass lawn to cross, the cost estimate is reasonable. For homes with very extensive landscaping such as large bushes and trees, underground sprinklers, or brick or concrete patios, sidewalks, and planters, the cost estimate for installation of PVC piping could be very low. Particular attention should be given to this cost item when costs are being developed for a specific installation.

Operation and Maintenance Requirements

Operation and maintenance requirements for point-of-use activated alumina fluoride removal are only for labor and material costs. Since the water pressure delivered to the home is sufficient for operation of the activated alumina filter, no electricity is required. The operation and maintenance requirements are separated into three cost categories: sampling/testing, media regeneration, and repairs.

A summary of operation and maintenance requirements is shown in Table 178. A range of requirements is shown for each cost category so that the level of sampling, frequency of regeneration, and level of repairs can be selected by the user of this cost information.

Labor requirements are for collecting samples of product water for fluoride analysis, for removing the filter for regeneration or replacement of activated alumina media, and for infrequent repairs of piping or filter leaks. The major sample/testing is to run fluoride tests on the product water. When the fluoride level rises above the MCl, the treatment cannister should be replaced with one containing regenerated or new activated alumina. Other types of testing which are occasionally performed on one or several of the point-of-use homes in a development are standard plate counts and total and fecal coliform testing.

TABLE 177. CONSTRUCTION COST SUMMARY FOR ACTIVATED ALUMINA POINT-OF-USE TREATMENT

	Construction Cost, $	
Cost Category	Installation Located Under Sink or in Basement	Installation Located Underground at the Property Line in a Meter Box
Activated Alumina Filter Cannister	$200	$200
Plastic Meter Box and 10 in PVC Pipe Collar	--	30
PVC Piping to House	--	20
Faucet, Copper or Plastic Tubing, and Fittings	40	40
Labor, Installation	40	120
Subtotal	280	410
Contingency	40	60
Total	$320	$470

Notes: 1. For an additional cost of $50, a bypass line and needle valve can be installed to blend treated and untreated water to achieve an acceptable contaminant level in the final product water.

2. For an additional cost of $40, a water meter can be installed after the treatment unit to record the amount of water treated and to help the utility estimate the unit life.

3. For property line installations, costs for PVC pipe to the house ($20) and installation of this line ($40) may be low for extensively landscaped yards.

Maintenance material requirements are for sampling, resin regeneration/replacement, and repair. Material requirements for sampling are for the costs of laboratory analyses for fluoride and bacterial counts. The costs are fairly low because it is assumed that a number of homes would be tested at the same time, lowering the per unit cost. The material requirement for regneration is actually for the entire cost of having the media regenerated or replaced; this cost is based on actual costs which are charged to the Arizona point-of-use communities for media regeneration.[1] The material cost for repairs is for infrequent replacement of a leaking piece of pipe or fitting or the fiberglass filter housing.

References

1. "EPA/NSF Study of Defluoridation of Drinking Water in Small Communities," Fourth Quarterly Report, September 15, 1982. EPA Contract No. R809248010.

2. "EPA/NSF Study of Defluoridation of Drinking Water in Small Communities," Fifth Quarterly Report, December 25, 1982. EPA Contract No. R809248010.

TABLE 178. OPERATION AND MAINTENANCE SUMMARY FOR ACTIVATED ALUMINA POINT-OF-USE TREATMENT

Cost Category	Labor, hr/yr	Materials, $/yr	Total Cost, $/yr Specific Condition	Total Cost, $/yr Mid-Range Condition
Sampling/Testing				
Frequency				
2/yr	2	20	41	
4/yr	6	40	106	$106
6/yr	12	60	192	
Media Regeneration				
Frequency				
2/yr	2	100	122	
1/yr	1	50	61	61
0.5/yr	0.5	25	30	
Repairs				
Low	1	10	21	
Average	2	20	42	42
High	3	30	63	
Total Cost for Mid-Range Condition =				$209/yr

Notes:
1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.
3. Materials costs for regeneration assume that the alumina is regenerated locally. If extensive shipping costs are incurred, the regeneration materials cost will have to be increased to account for this shipping. Round trip shipping costs between Illinois and Arizona for the same size canister used in this table, are $14.00.[2]

GRANULAR ACTIVATED CARBON POINT-OF-USE TREATMENT

Introduction

Granular activated carbon (GAC) contactors can be used for point-of-use removal of organics, as well as for mercury. Typically, GAC contactor units are designed to be installed under a kitchen sink and to provide water through a separate tap or faucet mounted on the sink. The treated water is used only for drinking and cooking, which prolongs the life of the carbon cartridge, since only about 1 to 2 gallons of water per day are used by a typical family.

GAC treatment should only be used on water known to be of acceptable bacterial quality. It is desirable to disinfect water prior to GAC treatment.

Construction Costs

Construction costs for point-of-use GAC contactors are presented in Table 179 for installations located under the kitchen sink and for installations at the property line. The cost for the contactor is based on using either a quality plastic or stainless steel housing and a replaceable carbon cartridge. The housing is 25 to 30 cm (10 to 12 in) long and 10 to 13 cm (4 to 5 in) in diameter.

Carbon quantities contained in the GAC contactor range from 0.002 to 0.003 m^3 (0.06 to 0.09 cu ft). The quantity of water which can be treated by the GAC filter unit, assuming the application is organics removal, will depend upon the concentration and type of organics in the untreated water. However, a reasonable range in treated water capacity is between 3,800 to 11,300 L (1,000 to 3,000 gal), based on the above carbon volumes.[1]

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements for point-of-use GAC contactors are only for labor and material costs. No electricity is required since the water pressure delivered to the home is sufficient for operation of the GAC contactor. The operation and maintenance requirements are separated into three cost categories: sampling/testing, carbon cartridge replacement, and repairs.

A summary of operation and maintenance requirements is shown in Table 180. A range of requirements is shown for each cost category so that the level of sampling, frequency of carbon replacement, and level of repairs can be selected by the user of this cost information.

Labor requirements are for collecting samples of contactor product water, for replacement of the GAC contactor cartridge, and for infrequent repairs of piping or contactor leaks. The major sample/testing would consist of testing for organics or a specific heavy metal contaminant such as mercury. When the organics or mercury contaminant level rises above the allowable limit, it is time to replace the carbon cartridge. Another type of testing done occasionally on GAC contactors is bacterial testing consisting of standard plate counts and total coliform tests. If the total coliform test is positive, a fecal coliform test should be conducted.

TABLE 179. CONSTRUCTION COST SUMMARY FOR GRANULAR ACTIVATED CARBON POINT-OF-USE TREATMENT

	Construction Cost, $	
Cost Category	Installation Located Under Sink or in Basement	Installation Located Underground at the Property Line in a Meter Box
GAC Contactor	$140	$140
Plastic Meter Box and 10 in PVC Pipe Collar	--	30
PVC Piping to House	--	20
Faucet, Copper or Plastic Tubing, and Fittings	40	40
Labor, Installation	40	120
Subtotal	220	350
Contingency	30	50
Total	$250	$400

Notes: 1. For an additional cost of $50, a bypass line and needle valve can be installed to blend treated and untreated water to achieve an acceptable contaminant level in the final product water.
2. For an additional cost of $40, a water meter can be installed after the GAC contactor to record the amount of water treated and to help the utility estimate the GAC contactor life.
3. For property line installations, costs for PVC pipe to the house ($20) and for installation of this line ($40) may be low for extensively landscaped yards.

Maintenance material requirements are for sampling, GAC contactor cartridge replacement, and for other repair components as required. Material requirements for sampling are the costs of the laboratory analyses required for organics tests and/or mercury tests and bacterial counts; these costs are based on actual costs which are incurred in a point-of-use GAC contactor evaluation in Pennsylvania.[2] The material cost for repairs is for infrequent replacement of a leaking piece of pipe or fitting, or the carbon contactor housing.

TABLE 180. OPERATION AND MAINTENANCE SUMMARY FOR GRANULAR ACTIVATED CARBON POINT-OF-USE TREATMENT

Cost Category	Labor, hr/yr	Materials, $/yr	Total Cost, $/yr Specific Condition	Total Cost, $/yr Mid-Range Condition
Sampling/Testing				
Frequency				
2/yr	2	60	82	
4/yr	4	120	164	$164
6/yr	6	180	246	
Carbon Cartridge Replacement				
Frequency				
1/yr	1	10	21	
2/yr	0.5	5	10	10
3/yr	0.3	3	6	
Repairs				
Low	1	10	21	
Average	2	20	42	42
High	3	30	63	

Total Cost for Mid-Range Condition = $216/yr

Notes: 1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.

References

1. "EPA/NSF Study of Defluoridation of Drinking Water in Small Communities and Point-Of-Use Reduction of Volatile Halogenated Organic Contaminants from Drinking Water," Seventh Quarterly Report, June 1983.

2. "Personal Communication," Randy Gottler, Research Assistant, National Sanitation Foundation, Ann Arbor, Michigan, November 21, 1983.

CATION EXCHANGE POINT-OF-USE TREATMENT

Introduction

Cation exchange can be used to remove a number of different contaminants, as shown in Table 174. Installations may be under the sink, or at the property line. Typical installations are shown in Figures 168 and 170.

Construction Costs

Construction costs for point-of-use cation exchange systems are presented in Table 181. The costs include a cation exchange cannister and resin, a special faucet, and all required tubing, fittings, and adaptors. The fiberglass cation exchange cannister is about 15 cm (6 in) in diameter by 58 cm (23 in) long, and contains an effective resin volume of 0.008 m^3 (0.3 cu ft).

The quantity of water of which can be treated by a cation exchange unit prior to regeneration depends upon the chemical composition of the water being treated, and the contaminants which are being removed. Assuming that removal of contaminants listed in Table 174 is proportional to hardness removal, a hardness concentration of 600 mg/L as $CaCO_3$, a resin exchange capacity of 144 kg of hardness as $CaCO_3$ per m^3 of resin (9 lb/cu ft of resin), a resin volume of 0.008 m^3 (0.3 cu ft) and a water use of 7.6 L (2 gal) per day, the unit could operate for 270 days prior to regeneration. For the same conditions except a water hardness of 200 mg/L as $CaCO_3$, the unit could operate for 810 days before regeneration. Pilot-scale testing should be performed to determine the actual regeneration frequency for a specific water supply.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements for point-of-use cation exchange units are only for labor and material costs. No electricity is required since the water pressure delivered to the home is sufficient for operation of the cation exchange unit. The operation and maintenance requirements are separated into three cost categories: sampling/testing, resin regeneration, and repairs.

A summary of operation and maintenance requirements is shown in Table 182. A range of requirements is shown for each cost category, so that the level of sampling, frequency of resin regeneration, and level of repairs can be selected by the user of this cost information.

Labor requirements are for collecting samples on cation exchange performance, replacement of exhausted resin cannisters with regenerated resin cannisters, off-site regeneration of exhausted resin or replacement of resin, and for infrequent repair of leaks in piping, fittings, or in the cation exchange unit. The major sampling/testing effort is to run tests for contaminants. When the contaminant concentration exceeds the MCL, the exhausted cannister should be replaced. Another type of testing done occasionally is bacterial testing, consisting of standard plate counts and total coliform tests. If the total coliform test is positive, a fecal coliform test should be conducted.

TABLE 181. CONSTRUCTION COST SUMMARY FOR CATION EXCHANGE POINT-OF-USE TREATMENT

	Construction Cost, $	
Cost Category	Installation Located Under Sink or in Basement	Installation Located Underground at the Property Line in a Meter Box
Cation Exchange Cannister and Resin	$180	$180
Plastic Meter Box and 10 in PVC Pipe Collar	--	30
PVC Piping to House	--	20
Faucet, Copper or Plastic Tubing, and Fittings	40	40
Labor, Installation	40	120
Subtotal	260	390
Contingency	40	60
Total	$300	$450

Notes: 1. For an additional cost of $50, a bypass line and needle valve can be installed to blend treated and untreated water to achieve an acceptable contaminant level in the final product water.

2. For an additional cost of $40, a water meter can be installed after the treatment unit to record the amount of water treated and to help the utility estimate the unit life.

3. For property line installations, costs for PVC pipe to the house ($20) and for installation of this line ($40) may be low for extensively landscaped yards.

Maintenance material requirements are for sampling, resin regeneration, and repairs. Material requirements for sampling are the costs of the laboratory analyses. The material costs for repairs is for infrequent replacement of a leaking piece of pipe or fitting or the cation exchange unit housing.

TABLE 182. OPERATION AND MAINTENANCE SUMMARY FOR CATION EXCHANGE POINT-OF-USE TREATMENT

Cost Category	Labor, hr/yr	Materials, $/yr	Total Cost, $/yr	
			Specific Condition	Mid-Range Condition
Sampling/Testing				
Frequency				
2/yr	2	40	62	
4/yr	4	80	124	$124
6/yr	6	120	186	
Resin Regeneration				
Frequency				
1/yr	1	30	41	
2/yr	0.5	15	21	21
3/yr	0.3	10	13	
Repairs				
Low	1	10	21	
Average	2	20	42	42
High	3	30	63	

Total Cost for Mid-Range Condition = $187/yr

Notes: 1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.

ANION EXCHANGE POINT-OF-USE TREATMENT

Introduction

Anion exchange units can be used to remove nitrate, as well as a number of other contaminants as listed in Table 174. Either under the sink or property line installations can be used, as illustrated in Figures 168 and 170, respectively.

Construction Costs

Construction costs for point-of-use anion exchange units are presented in Table 183. The cost of the anion exchange unit is based on using a fiberglass housing and a replaceable anion exchange resin cartridge. The housing is 16 cm (6 1/4 in) in diameter by 58 cm (23 in) long and has a resin capacity of 0.008 m^3 (0.3 cu ft). The quantity of water which can be treated by the anion exchange unit depends upon the contaminant which is being removed. For nitrate removal applications, the quantity treated is a function of nitrate, sulfate, and total anion concentrations. The anion exchange resin preferentially removes sulfate over nitrate; therefore when the exchange sites are filled, the unit will begin to release nitrate, and an increase in the nitrate concentration will occur in the effluent from the unit. For a nitrate concentration of 100 mg/L as nitrate, or 23 mg/L as N, and a 100 mg/L sulfate concentration, the nitrate exchange capacity is 15.3 kg/m^3 (6,700 grains per cu ft) of exchange resin. For an anion exchange resin volume of 0.008 m^3 (0.3 cu ft) the nitrogen removal capacity is 0.13 kg (0.29 lb) of nitrogen. At a water usage of 7.5 L (2 gal) per day the total nitrogen feed rate is $1.7x10^{-4}$ kg/d ($3.8x10^{-4}$ lb/day) of nitrogen, resulting in a resin life of 763 days, or about three years. During this time period the anion exchange resin removes both sulfate and nitrate from the feed water.

Operation and Maintenance Requirements and Costs

Operation and maintenance requirements for point-of-use anion exchange units are only for labor and material costs. No electricity is required since the water pressure delivered to the home is sufficient for operation of the anion exchange unit. The operation and maintenance requirements are separated into three cost categories: sampling/testing, anion exchange resin regeneration, and repairs.

Labor requirements are for collecting samples on the anion exchange unit product water, for replacement of the anion exchange resin, and for infrequent repairs of leaks in the piping or the anion exchange unit. The major sample/testing is for nitrate concentration. When the nitrate concentration begins to rise above the MCL, it is time to replace the anion exchange resin. Another type of testing done occasionally on anion exchange units is bacterial testing consisting of standard plate counts and total coliform tests. If a total coliform test is positive, a fecal coliform test is conducted.

Maintenance material requirements are for sample collection, replacement resin, and miscellaneous repair parts. For resin, either complete replacement or regeneration should be used, whichever is the more cost-effective approach.

TABLE 183. CONSTRUCTION COST SUMMARY FOR ANION EXCHANGE POINT-OF-USE TREATMENT

	Construction Cost, $	
Cost Category	Installation Located Under Sink or in Basement	Installation Located Underground at the Property Line in a Meter Box
Anion Exchange Cannister and Resin	$270	$270
Plastic Meter Box and 10 in PVC Pipe Collar	--	30
PVC Piping to House	--	20
Faucet, Copper or Plastic Tubing, and Fittings	40	40
Labor, Installation	40	120
Subtotal	350	480
Contingency	50	70
Total	$400	$550

Notes:
1. For an additional cost of $50, a bypass line and needle valve can be installed to blend treated and untreated water to achieve an acceptable contaminant level in the final product water.
2. For an additional cost of $40, a water meter can be installed after the treatment unit to record the amount of water treated and to help the utility estimate the unit life.
3. For property line installations, costs for PVC pipe to the house ($20) and for installation of this line ($40) may be low for extensively landscaped yards.

Material requirements for sampling are the costs of the laboratory analyses required for nitrate tests and bacterial counts. The material costs for repairs is for infrequent replacement of a leaking piece of pipe or fitting or the anion exchange unit housing.

A summary of operation and maintenance requirements in shown in Table 184. A range of requirements is shown for each cost category, so that the level of sampling, frequency of resin regeneration, and level of repairs can be selected by the user of this cost information.

TABLE 184. OPERATION AND MAINTENANCE SUMMARY FOR ANION EXCHANGE POINT-OF-USE TREATMENT

Cost Category	Labor, hr/yr	Materials, $/yr	Total Cost, $/yr Specific Condition	Total Cost, $/yr Mid-Range Condition
Sampling/Testing				
Frequency				
2/yr	2	40	62	
4/yr	4	80	124	$124
6/yr	6	120	186	
Resin Regeneration				
Frequency				
1/yr	1	60	71	
2/yr	0.5	30	36	36
3/yr	0.3	20	23	
Repairs				
Low	1	10	21	
Average	2	20	42	42
High	3	30	63	

Total Cost for Mid-Range Condition = $202/yr

Notes: 1. Materials cost for sampling/testing represents the cost for laboratory testing.
2. Total cost is based upon $11.00/hour of labor.

SECTION 7

EXAMPLE CALCULATIONS USING THE COST DATA

INTRODUCTION

To demonstrate the use of the construction and operation and maintenance cost data included in this report, several examples have been prepared. These examples are:

- 0.5 mgd Conventional Package Complete Water Treatment Plant
- 1.0 mgd Reverse Osmosis Plant
- 0.75 mgd Package Pressure Filtration Plant

In each example, the plant operating rate is 70% of the plant design capacity.

These examples were developed for hypothetical situations, and the design criteria and costs presented should be considered as general in nature and not necessarily applicable to all plants having the same design capacity, flow rate, and treatment processes as the examples.

The examples illustrate the method of adding a number of special costs to the subtotal obtained from the construction cost curves, to develop the total capital cost for a project. These special costs are added to the subtotal of the construction cost for all of the unit processes in the plant, since they are more appropriately related to the subtotal of construction cost than to the construction cost of each individual unit process. These special costs include: (1) special sitework, landscaping, roads, and interface piping between processes; (2) special subsurface considerations; and (3) standby power. The special costs will vary widely depending on the site, the design engineer's preference, and regulatory agency requirements. Addition of these special costs to the subtotal cost of the unit processes gives the total construction cost.

To arrive at the total capital cost, the following costs must then be added to the total construction cost: (1) general contractor's overhead and profit, (2) engineering costs, (3) land costs, (4) legal, fiscal, and administrative costs, and (5) interest during construction. Contractor's overhead and profit will vary with the size of the job, the complexity of the job, and the bidding competition. Engineering costs will vary with the need for preliminary studies, time delays, the size and complexity of the project, and any construction-related inspection and engineering design activities. A curve showing typical values for legal, fiscal, and administrative costs is shown in Figure 171 and curves for interest during construction at rates of 8, 10 and

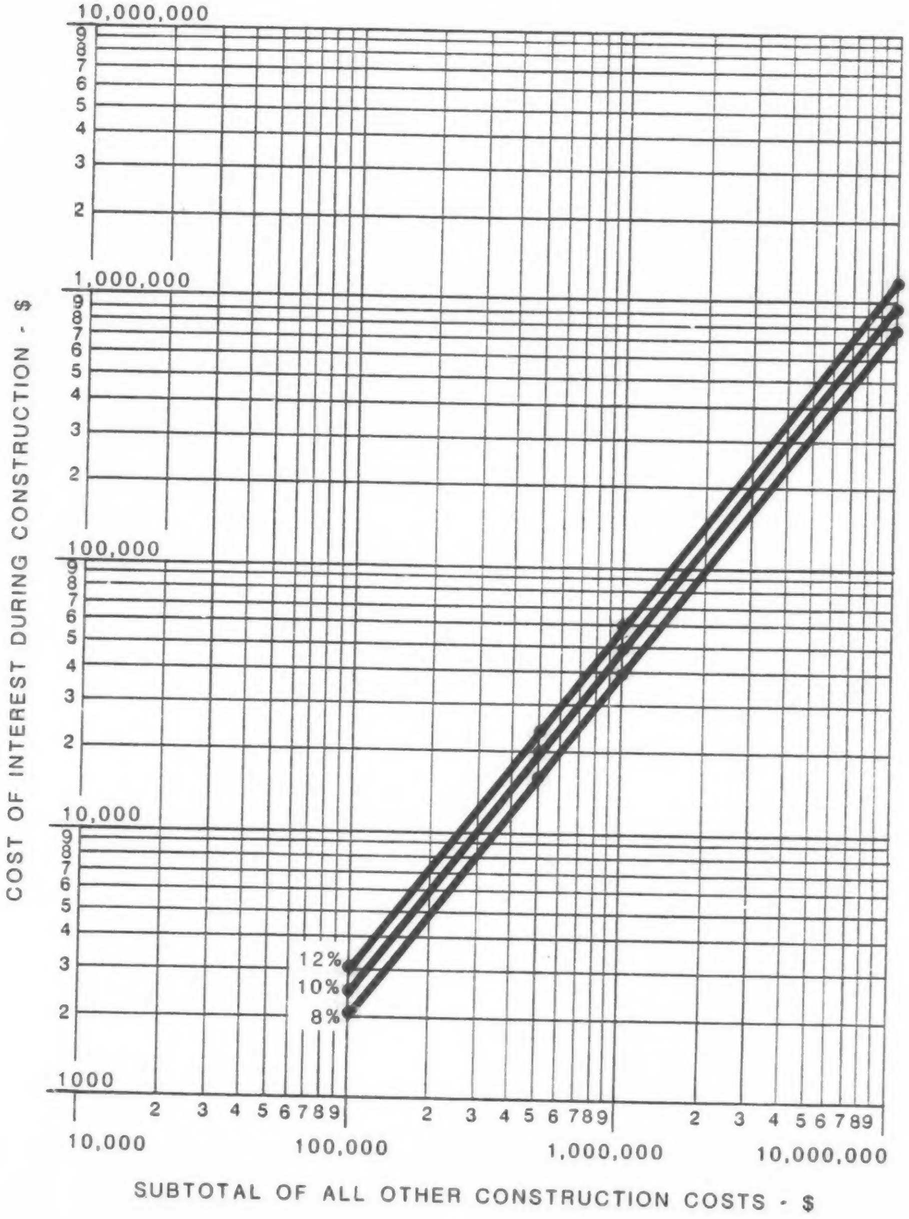

Figure 171. Legal, fiscal, and administrative costs.

12% are shown in Figure 172. The cost of interest during construction, which represents the interest cost accrued on funds from the time payment is made to the contractor until the end of the construction, is a function of the interest rate and the duration of construction. The following construction durations were utilized.

Total Construction Cost, $	Total Construction Duration, Months
100,000	6
500,000	10
1,000,000	13
10,000,000	24

Operation and maintenance costs in the following examples are based upon an electrical cost of $0.07/kwh and a labor cost of $11.00/hr. Unit costs for chemicals are shown in the tables for each example.

0.5 MGD CONVENTIONAL PACKAGE COMPLETE WATER TREATMENT PLANT

Package complete treatment plants include coagulation, flocculation, sedimentation, and filtration, all included in factory pre-assembled units or field-assembled modules. Their relatively low initial cost, as well as the low operation and maintenance cost that results from automatic control features, makes package complete treatment facilities popular for small installations. This example presents costs for a conventional package complete plant including raw water pumping, alum, polymer, and gas chlorine feed, sludge disposal to a sanitary sewer, clearwell storage and high-service pumping.

Table 185 presents design criteria, initial capital cost, and operation, and maintenance requirements for a 1893 m^3/d (0.5 mgd) conventional package complete water treatment plant. The plant is operating at a flow rate of 1325 m^3/d (0.35 mgd) which is 70% of the design capacity. Alum, polymer, and chlorine design feed rates and operating feed rates are presented in the table.

Table 186 illustrates the development of the total annual cost and a unit cost per volume of water treated. The cost of chemicals is included in Table 186. As illustrated, the unit cost is $0.299/$m^3$ ($1.13/1,000 gallons) treated.

1.0 MGD REVERSE OSMOSIS PLANT

Reverse osmosis treatment can be used to reduce the dissolved solids content of brackish water supplies, as well as to remove a substantial number of contaminants included in the National Interim Primary Drinking Water Regulations. This example is for a 3785 m^3/d (1 mgd) reverse osmosis system, an unlined brine evaporation pond, clearwell storage and gas feed chlorination. The plant is assumed to be operating at 2650 m^3/d (0.7 mgd), or 70% of design capacity.

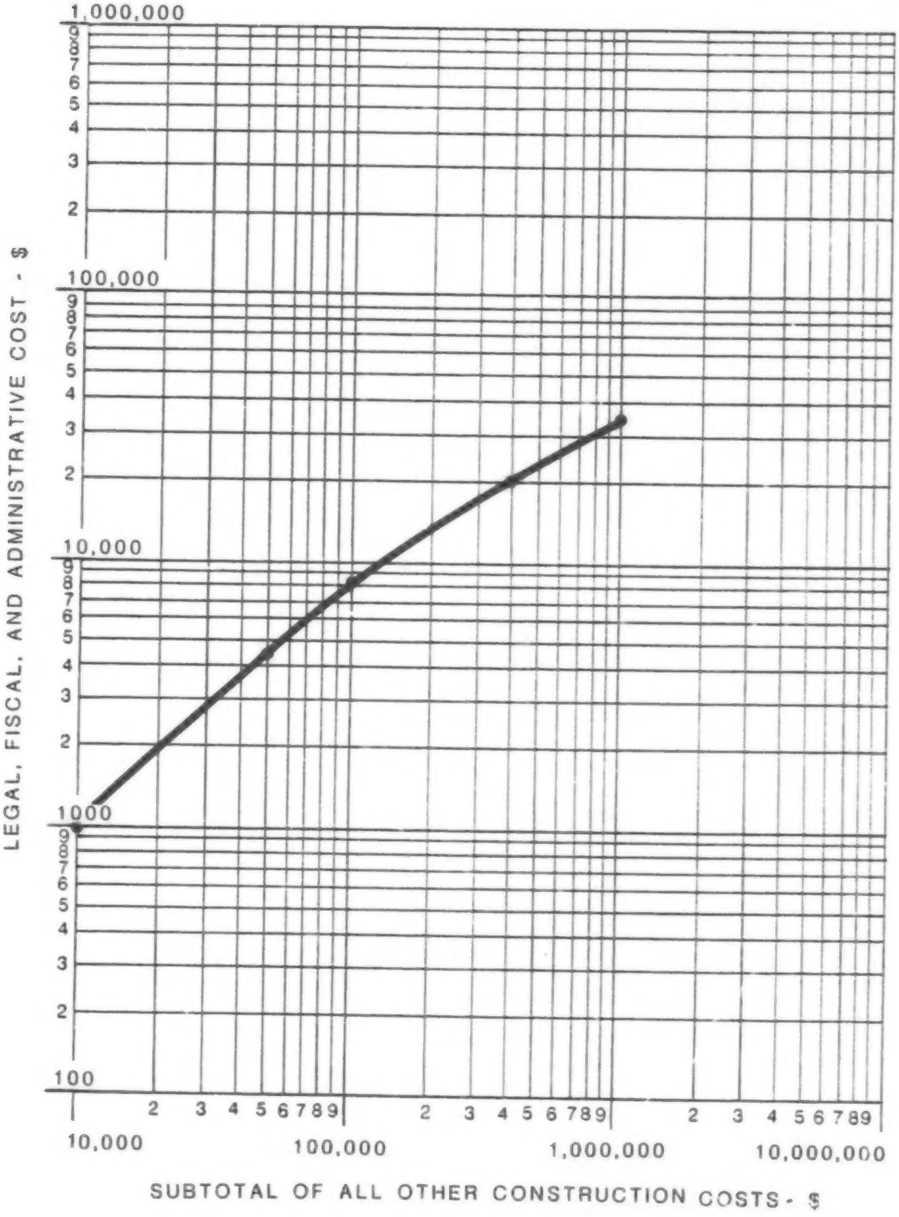

Figure 172. **Cost of interest during construction.**

TABLE 185. DESIGN CRITERIA AND COST CALCULATION FOR A 0.5 MGD CONVENTIONAL PACKAGE COMPLETE TREATMENT PLANT OPERATING AT 0.36 MGD

System and Design Criteria	Figure Numbers	Design Parameter	Construction Cost	Operating Parameter	Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr
Package Raw Water Pumping Facilities	151,152,153	720,000 gpd	$ 44,400	345,600 gpd	28,200	200	70
Conventional Package Complete Treatment Plant - 4 gpm/sq ft, 2 backwashes/day	2,3,4	87 sq ft	350,500	60 sq ft	27,800	4,500	1,200
Gas Feed Chlorination	80,81,82	12.5 lb/day	20,200	4.3 lb/day	2,900	400	180
Clearwell Storage, Above Ground, Steel	167	125,000 gal	95,300	125,000 gal	-0-	-0-	-0-
Package High-Service Pumping	154,155,156	720,000 gpd	31,800	345,600 gpd	105,300	100	130
Sludge Disposal, Sanitary Sewer, 5000 gpd	138	16,800 mg/L	-0-	16,800 mg/L	-0-	19,100	-0-
Subtotal	--	--	542,200		164,200	24,300	1,580
Sitework, Interface Piping, Roads @ 5%	--	--	27,100				
Subsurface Considerations	--	--	-0-				
Standby Power	--	--	-0-				
Total Construction Cost	--	--	569,300				
General Contractor's Overhead and Profit @ 12%	--	--	68,300				
Subtotal	--	--	637,600				
Engineering @ 10%	--	--	63,800				
Subtotal	--	--	701,400				
Land, 0.6 acres @ $2,000/acre	--	--	1,200				
Legal, Fiscal and Administrative	--	--	12,600				
Interest during Construction - 10%	--	--	35,600				
Total Capital Cost	--	--	$750,800				

NOTES: (1) Figure numbers refer to figures in the report.
(2) Alum, polymer and chlorine feed systems are based upon the following design and operating feed rates:

Chemical	Design Feed Rate - mg/L	Operating Feed Rate - mg/L
Alum	--	20
Polymer	--	0.2
Chlorine	3.0	1.5

(3) For sludge disposal, sanitary sewer, the annual cost is presented in the maintenance material category.

TABLE 186. ANNUAL COST FOR A 0.5 MGD PACKAGE COMPLETE TREATMENT PLANT OPERATING AT 0.35 MGD

Item	Total Costs/yr
Amortized Capital @ 10%, 20 years	$ 88,200
Electricity, 162,600 kwh/yr @ $0.07	11,400
Maintenance Material	24,300
Labor, 1,580 hr @ $11/hr (Total Labor Costs including fringes and benefits)	17,400
Chemicals, Alum, 10.52 tons/yr @ $150/ton;	1,600
Polymer 210 lb/yr @ $2/lb;	400
Chlorine, 0.79 tons/yr @ $300/ton	300
Total Annual Cost	$143,600

$$\text{Dollars per 1,000 gal treated} = \frac{\$\,143{,}600}{350\ (365)}$$

$$= \$1.13/1{,}000 \text{ gal treated}$$

NOTE: Chemical costs are based on the following dosages: alum - 20 mg/L; polymer - 0.2 mg/L; chlorine - 1.5 mg/L.

Table 187 presents the design criteria, initial capital cost, and operation and maintenance requirements. The development of a unit cost of $0.586/m^3 ($2.218/1,000 gallons) treated is illustrated in Table 188. Chemical dosages are also presented in Table 188.

0.75 MGD PACKAGE PRESSURE FILTRATION PLANT

Package pressure filtration is often used in small water treatment applications where prior coagulation and sedimentation is not necessary. This example is for such a situation, and includes raw water pumping, polymer feed, pressure filtration using mixed media at a rate of 12.2 $m^3/m^2/h$ (5 gpm/sq ft), clearwell storage, and high-service pumping. Sludge and backwash water are discharged to a sludge lagoon, and it was assumed that periodic sludge removal would be unnecessary because of the small quantity of solids being removed. The plant design capacity is 2839 m^3/d (0.75 mgd) and the plant operating rate is 1987 m^3/d (0.53 mgd).

Design criteria, capital cost, and operation and maintenance requirements are shown in Table 189. Chemical design feed rates and operating feed rates are also shown in this table. The unit cost of treatment, including chemical costs, is $0.146/m^3 ($0.555/1,000 gallons) treated, as shown in Table 190.

TABLE 187. DESIGN CRITERIA AND COST CALCULATION FOR A 1.0 MGD REVERSE OSMOSIS PLANT OPERATING AT 0.7 MGD

System and Design Criteria	Figure Numbers	Design Parameter	Construction Cost	Operating Parameter	Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr
Reverse Osmosis - High Pressure, 5000 mg/L TDS Feed	37,38,39	1.0 mgd	$1,167,000	0.7 mgd	2,213,000	88,200	840
Brine Evaporation Lagoons, No Liner	144,145	650,000 sq ft	376,800	650,000 sq ft	-0-	1,200	140
Clearwell Storage - Above Ground, Steel	167	125,000 gal	95,300	125,000 gal	-0-	-0-	-0-
Gas Feed Chlorination	80,81,82	25.0 lb/day	20,200	88 lb/day	3,000	400	180
Package High-Service Pumping	154,155,156	1.25 mgd	40,800	0.7 mgd	208,300	200	140
Subtotal	--	--	1,700,100		2,424,300	90,000	1,300
Sitework, Interface Piping, Roads @ 5%	--	--	85,000				
Subsurface Considerations	--	--	-0-				
Standby Power	--	--	-0-				
Total Construction Cost	--	--	1,785,100				
General Contractor's Overhead and Profit @ 12%	--	--	214,200				
Subtotal	--	--	1,999,300				
Engineering @ 10%	--	--	199,900				
Subtotal	--	--	2,199,200				
Land, 17.5 acres @ $2,000/acre	--	--	33,000				
Legal, Fiscal and Administrative	--	--	25,800				
Interest during Construction - 10%	--	--	166,900				
Total Capital Cost	--	--	2,424,900				

NOTES: (1) Figure numbers refer to figures in this report.
(2) The gas chlorination feed system design parameter is based upon a feed rate of 3.0 mg/L, and the operating parameter is based upon 1.5 mg/L.

TABLE 188. ANNUAL COST FOR A 1.0 MGD REVERSE OSMOSIS PLANT OPERATING AT 0.70 MGD

Item	Total Costs/yr
Amortized Capital @ 10%, 20 years	$284,800
Electricity, 2,424,300 kwh/yr @ $0.07	169,700
Maintenance Material	90,000
Labor, 1,300 hr @ $11/hr (Total Labor Costs including fringes and benefits)	14,300
Chemicals, Alum, 26.64 tons/yr @ $80/ton;	2,100
Sodium Hexametaphosphate, 5.32 ton/yr @ $1,000/ton;	5,300
Chlorine, 1.60 tons/yr @ $300/ton	500
Total Annual Cost	$566,700

$$\text{Dollars per 1,000 gal treated} = \frac{\$\ 566,700}{700\ (365)}$$

$$= \$2.218/1,000 \text{ gal treated}$$

NOTE: Chemical costs are based on the following dosages: sulfuric acid - 25 mg/L; sodium hexametaphosphate - 5 mg/L; and chlorine - 1.5 mg/L.

TABLE 190. ANNUAL COST FOR A 0.7 MGD PRESSURE FILTRATION PLANT OPERATING AT 0.53 MGD

Item	Total Costs/yr
Amortized Capital @ 10%, 20 years	$ 75,200
Electricity, 221,000 kwh/yr @ $0.07	15,500
Maintenance Material	2,000
Labor, 1,000 hr @ $11/hr (Total Labor Costs including fringes and benefits)	11,000
Chemicals: Polymer, 323 lb/yr @ $2/lb;	700
Chlorine, 1.2 tons/yr @ $300/ton	400
Total Annual Cost	$104,800

$$\text{Dollars per 1,000 gal treated} = \frac{\$\ 104,800}{530\ (365)}$$

$$= \$0.542/1,000 \text{ gal treated}$$

NOTE: Chemical costs are based on the following dosages: polymer - 0.2 mg/L and chlorine - 1.5 mg/L.

TABLE 189. DESIGN CRITERIA AND COST CALCULATION FOR A 0.75 MGD PACKAGE PRESSURE FILTRATION PLANT OPERATING AT 0.53 MGD

System and Design Criteria	Figure Numbers	Design Parameter	Construction Cost	Operating Parameter	Energy, kwh/yr	Maintenance Material, $/yr	Labor, hr/yr
Package Raw Water Pumping Facilities	151,152,153	1,000,000 gpd	$ 52,400	530,000 gpd	42,800	200	80
Polymer Feed System - Single Tank	113,114,115	6.3 lb/day	5,100	0.83 mg/L	300	100	250
Pressure Filtration Plant, 5 gpm/sq ft, 2 backwashes/day	16,17,18	104 sq ft	235,300	74 sq ft	16,200	1,100	350
Gas Feed Chlorinator	80,81,82	18.8 lb/day	20,200	6.6 lb/day	2,900	400	180
Clearwell Storage - Ground Level	167	150,000 gal	106,800	150,000 gal	-0-	-0-	-0-
Package High-Service Pumping	154,155,156	1,000,000 gal	37,000	530,000 gal	158,800	200	140
Sludge Storage Lagoon	135,136,137	15,000 cu ft	5,500	0 cu ft/yr	-0-	-0-	-0-
Subtotal	--	--	462,300		221,000	2,000	1,000
Sitework, Interface Piping, Roads @ 5%	--	--	23,100				
Subsurface Considerations	--	--	-0-				
Standby Power	--	--	-0-				
Total Construction Cost	--	--	485,400				
General Contractor's Overhead and Profit @ 12%	--	--	58,300				
Subtotal	--	--	543,700				
Engineering @ 10%	--	--	54,400				
Subtotal	--	--	598,100				
Land, 1.0 acres @ $2,000/acre	--	--	2,000				
Legal, Fiscal and Administrative	--	--	11,700				
Interest during Construction - 10%	--	--	28,000				
Total Capital Cost	--	--	$639,800				

NOTES: (1) Figure numbers refer to figures in the report.
(2) Polymer and chlorine feed systems are based upon the following design and operating rates:

Chemical	Design Feed Rate - mg/L	Operating Feed Rate - mg/L
Polymer	1.0	0.2
Chlorine	3.0	1.5

SECTION 8

COMPUTER PROGRAM FOR COST DATA RETRIEVAL AND UPDATING

INTRODUCTION

This section is a computer program users manual and contains documentation and user information for the WATER program, which is a FORTRAN computer program that retrieves and updates cost information for the 45 unit processes presented in Section 5 of this report. Costs can also be determined for entire treatment plants, and they are input to the program as trains of individual unit processes.

Background

The WATER program described here can be used as a valuable tool to facilitate retrieval and updating of the cost information presented in this report. Since WATER has been designed to compute costs for entire treatment plants, cost determinations for alternative treatment trains or regional variations in operating costs for a particular treatment train can be made quickly and accurately. This program is identical to a program presented in Volume 4 of a previous report[22] titled "Estimating Water Treatment Costs." The only difference is the data file named CRV.DAT. This data file is explained subsequently in this section.

The costs generated by this program are broken down into capital costs and operation and maintenance costs. Capital costs include the costs for construction, general contractor's overhead and profit, engineering, sitework and interface piping, subsurface considerations, standby power, legal, fiscal and administrative services, interest during construction, and land. Operation and maintenance costs include electricity, labor, maintenance materials, diesel fuel, natural gas, and chemicals. Most costs are stored as coefficients of third-degree polynomial expressions determined by the method of least squares for the values in the cost tables presented in Section 5. Therefore, the cost generated for a specific point in these tables could vary by as much as 10 to 20 percent from the value generated by the program, depending on the deviation of the values in the table from a smooth curve fit. In general, the differences between the costs generated by the program and the costs obtained through use of the cost data in Section 5, will be insignificant.

The user need not be an experienced programmer, but a familiarity with programming is recommended.

PURPOSE AND OBJECTIVES

The purpose of this section is to present complete documentation and user information for the FORTRAN computer program, WATER, which retrieves and updates cost information for the 45 unit processes presented in Section 5 of this report. The WATER program has been designed to facilitate the estimation of overall treatment plant costs as well as individual process costs.

INPUT DATA FILES

Three data files are necessary to run this program. Two of these files, COST.DAT and PROCES.DAT, are set up by the user. The third data file, CRV.DAT, is a construction and operation and maintenance cost data base containing information about each of the water treatment processes included in this report. This file is an integral part of the program and must be established on the computing system with the main program. Once it is established, the general user should have no need to access the main program, WATER, or the data base, CRV.DAT.

The first of the two data files to be constructed by the user is the COST.DAT file. Table 191 is an example listing of the COST.DAT file. This file basically contains all the cost information necessary to run the program. The variables in this file, called cost factors, must be input in the sequence shown in Table 191. A detailed explanation of the input format is given in the following discussion on COST.DAT File Construction.

The second file to be constructed by the user is the PROCES.DAT file. Table 192 is an example listing of the PROCES.DAT file. This file contains information about each of the water treatment processes for which the user desires costs. A detailed explanation of the input format is given in a following discussion called PROCES.DAT File Construction.

COST.DAT FILE CONSTRUCTION

To aid in understanding the format of this data file, the user is referred to Table 191, which must be constructed as shown. Lines 2, 10, and 16 are for user information only and are skipped by the program when reading this file. They must not be omitted, however, or the program will skip actual data. A line-by-line explanation of this file is given in Table 193.

PROCES.DAT FILE CONSTRUCTION

The PROCES.DAT file contains design and operating information about each of the processes for which the user may desire costs. This file can either be stored on the computer as a data file, or can be input as a deck of cards. The following discussion assumes a data file is used, and all reference is to lines rather than cards. Table 194 lists the processes for which costs are available and includes the process parameter range over which cost information is stored in the computer. For example, process 1 ACT ALUM FLUORIDE REM, RFREQ 4.5, has cost information stored in the program data file over a range of 32 to 753 cu ft of contactor volume. Also shown in Table 194 are the number of chemicals used in the treatment process, the process type and the number of data lines.

TABLE 191. COST.DAT FILE EXAMPLE

```
COSTS PRESENTED ARE CURRENT AS OF DECEMBER 1983
CAPITAL COST FACTORS (% OF CONSTRUCTION COST):
 1  ENGINEERING (%)                    =10.
 2  SITEWORK, INTERFACE PIPING (%)     =5.
 3  SUBSURFACE CONSIDERATIONS (%)      =0.0
 4  STANDBY POWER (%)                  =0.0
 5  INTEREST RATE (%)                  =10.0
 6  NUMBER OF YEARS                    =20.0
 7  LAND COST, $/ACRE                  =2,000.
UNIT COST FACTORS:
 8  ELECTRICITY, $/KWH                 =.07
 9  LABOR, $/HR                        =11.
10  DIESEL FUEL, $/GAL                 =1.10
11  NATURAL GAS, $/CU FT               =.0055
12  BLDNG ENERGY USE, KWH/SQ FT/YR     =19.5
COST INDICES:
13  EXCAVATION (ENR SKILLED LABOR)     =368.68
14  MANUFACTURED EQUIP (BLS #114)      =309.3
15  CONCRETE (BLS #132)                =317.0
16  STEEL (BLS #1017)                  =359.5
17  LABOR (ENR SKILLED LABOR)          =368.68
18  PIPE & VALVES (BLS #1149)          =327.0
19  ELECTRICAL & INSTR (BLS #117)      =243.7
20  HOUSING (ENR BUILDING COST)        =356.30
21  PRODUCER PRICE INDEX               =287.1
22  ENR CONSTRUCTION, '67 BASE YR      =0.0
OUTPUT (6 FOR LP, 5 FOR TELETYPE)      =5
PRINTOUT (DETAILED OR SUMMARY)         =SUMMARY
9,2
7.5,12.5
```

Chemical cost information is input along with process design and operating parameters, as explained later. The number of chemicals used in the process is listed in Table 194, and in most cases, the types of chemicals used will be obvious (for example, chlorine is used in process 23 GAS FEED CHLOR., TO 40 LB/DAY). For convenience, however, Table 195 lists the processes that use chemicals and the chemicals used.

The Process Type listed in Table 194 denotes the manner in which information is input to the computer, and the number of data lines indicates the number of lines necessary to input information for that process. The input data for each type are described later in this section.

Since the computer program is designed to determine individual process costs and plant costs by totaling the process costs, the PROCES.DAT file is assembled into what is here termed loosely as "segments" of data (Figure 173).

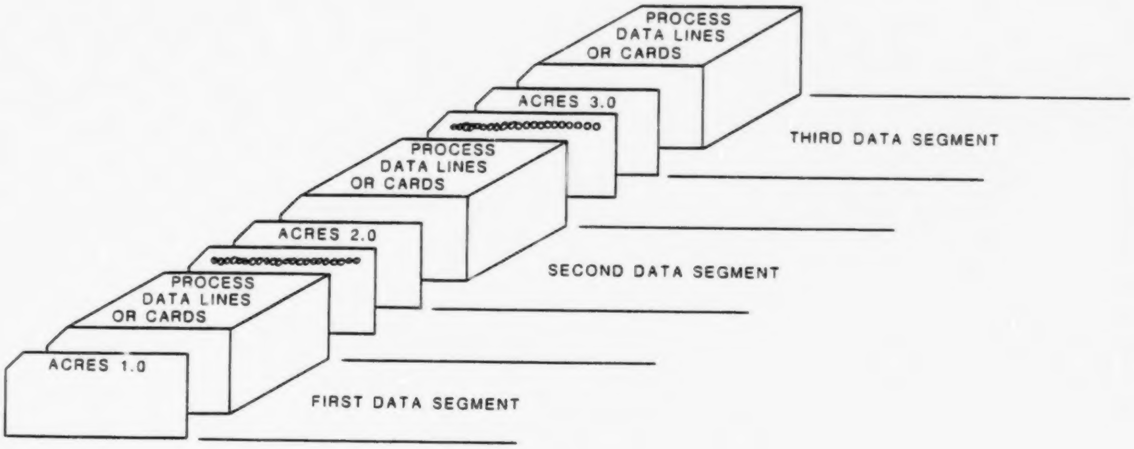
PROCESS
DATA LINES
OR CARDS
ACRES 3.0
THIRD DATA SEGMENT
PROCESS
DATA LINES
OR CARDS
ACRES 2.0
SECOND DATA SEGMENT
PROCESS
DATA LINES
OR CARDS
ACRES 1.0
FIRST DATA SEGMENT

Figure 173. PROCES.DAT data segments.

TABLE 192. PROCES.DAT FILE EXAMPLE

```
ACRES=1.5
1,19,REVERSE OSMOSIS, TDS 5000 MG/L
2,1.0,0.7,1000000.,700000.
3,80.,116.8,SULFURIC ACID-20 MG/L
4,1000.,29.2,HEXAMETAPHOSPHATE-5 MG/L
5,0.,0.
1,59,GROUND-LEVEL STEEL CLEARWELLS
2,1.0,0.7,125000.,125000.
1,23,GAS FEED CHLOR., TO 40 LB/DAY
2,1.0,0.7,25.0,8.8
3,300.,CHLORINE GAS
1,30,PACKAGE HIGH SERVICE PUMPING STA
2,1.0,0.7,1250000.,700000.
0000000000000000000000000000000000000000
ACRES=0.5
1,65,CONVEN. PCKG COMPL,2 GPM/SF,1 BW
2,0.43,0.32,150.,112.
3,180.0,67.2,ALUM-40 MG/L
4,0.0,0.0,POLYMER (NONE)
```

The ACRES= Line

Each data segment corresponds to a treatment plant and must begin with the ACRES= line. This line denotes the land area, in acres, required for the plant. If land costs are not to be included, the line should read ACRES=0.0, with the "A" in acres beginning in Column 1.

Process Data Lines

Following the ACRES= line, data lines for the processes in the plant are assembled sequentially. There may be as many processes as desired, in any order, and processes may be input more than once. The set of process data lines preceded by the ACRES= line constitutes a segment of data (Figure 173).

The Zero Line

Segments of data in the PROCES.DAT file must be separated by a line containing a string of at least 15 zeros. (In some systems, a blank line may suffice).

If cost data are desired for only one plant or segment of data, no ZERO line should be included. Inclusion of cost data for two or more plants requires that the PROCES.DAT file be arranged as shown in Figure 173, with ZERO lines between each segment.

TABLE 193. LINE-BY-LINE EXPLANATION OF COST.DAT FILE

Line No.	Explanation
1	First 48 characters printed "as is" on the program output. Intended to be used to denote valid date of cost information produced.
2	For user information only. This line is skipped by the program.
3-9	Capital cost factors as shown. Program read skips the first 34 characters then reads floating point number input. These values must start in Column 35 and must contain a decimal point. Percentage values, as indicated, must be percentages, not decimal values. Example: Engineering must be listed as 10.0 for 10 percent, not as 0.10. The program internally divides by 100.
10	For user information only - skipped by program read.
11-15	Unit cost factors as shown. As with lines 3-9, program read skips the first 34 characters. Values must begin in Column 35 and must contain decimal points. Units are as shown in Table 191. Building energy requirements in the CRV.DAT file are based up on either 156 kwh/m^2/yr (14.5 kwh/sq ft/yr) or 209.8 kwh/m^2/yr (19.5 kwh/sq ft/yr). This data is from the tables presented in Section 5 of this report. However, the data has been normalized in the CRV.DAT file to a value of 209.8 kwh/m^2/yr (19.5 kwh/sq ft/yr). If building energy requirements are expected to be higher than shown in Appendix A, the value entered on line 15 should be adjusted. For example, if building energy requirements are anticipated to be 50 percent higher than shown in Appendix A, 29.25 (which is 19.5 x 1.5) should be entered on line 15. If 19.5 is entered, the values should compare within 15 percent of the building energy requirements presented in the tables in Section 5.
16	For user information only - skipped by program read.
17-26	Cost indices as shown. As with lines 3-9 and 11-15, program read skips the first 34 characters. Values must begin in Column 35 and must contain decimal points. These cost indices are used to update the cost data base stored in the CRV.DAT file. The user has the option of using the first eight cost indices listed (Excavation through

(continued)

TABLE 193 (continued)

Line No.	Explanation
	Housing) to update the construction costs produced by the program, or he can use the ENR Construction Cost Index (line 26) in lieu of the first eight indices. The computer will use the ENR Construction Cost Index if the value input is greater than zero. If the value input for the ENR Construction Cost Index is equal to zero, the computer will use the first eight indices.
27	This line designates the location for program output. On most computer installations, a "5" designates the teletype or remote terminal. The program output is 132 characters wide, so it is suggested that the line printer be used if the teletype does not have the capacity to print 132 characters per line. The value for this variable must be an integer and must begin in Column 35.
28	This line designates a detailed or summary output. See subsequent discussions titled "Program Output" for an explanation of these options.
29-30	These lines are optional. The user may wish to run the program while varying only one of the cost factors in the COST.DAT file. Cost factors are numbered 1 through 22 for convenience. For example, cost factor number 9 is labor ($/hr). Thus if the user wants to determine the change in overall operation and maintenance cost based on the regional variation of the cost of labor across the nation, he first inputs in line 29 the number of the cost factor and the additional number of values to be used for that cost factor. In this case, lines 29 and 30 are as follows for two additional values of cost factor number 9: Line 29: 9,2 Line 30: 7.5,12.5 Line 30 contains the two additional values of labor ($/hr), which are 7.5 and 12.5. Note that all input values begin in column one for lines 29 and 30, and that they are separated by a comma. Up to 10 additional values may be input. They must be floating point numbers with decimal points, but they can appear in any column as long as they are separated by a

(continued)

TABLE 193 (continued)

Line No.	Explanation
	comma. Lines 29 and 30 shown in the listing of the COST.DAT file in Table 191 accomplish the following: The program computes all costs with the cost of labor ($/hr) at 11. Then the program is automatically rerun twice with the cost of labor ($/hr) at 7.5 and 12.5. This produces three complete printouts. If the user wants to run the program only once, without varying any of the 22 cost factors, lines 29 and 30 are omitted, and the designation of DETAILED or SUMMARY printout is the last card of the COST.DAT file.

TABLE 194. PROCESS PARAMETER RANGE, NUMBER OF CHEMICALS AND PROCESS TYPE

TREATMENT PROCESS	PARAMETER RANGE	NUMBER OF CHEMICALS	PROCESS TYPE	NO. DATA LINES
1 ACT ALUM FLUORIDE REM, RFREQ 4.5	32.0 TO 753.0 CU FT	2	2	4
2 ACT ALUM FLUORIDE REM, RFREQ 8	32.0 TO 753.0 CU FT	2	2	4
3 ACT ALUM FLUORIDE REM, RFREQ 12	32.0 TO 753.0 CU FT	2	2	4
4 ACT ALUM FLUORIDE REM, RFREQ 19	32.0 TO 753.0 CU FT	2	2	4
5 ACT ALUM FLUORIDE REM, RFREQ 33	32.0 TO 753.0 CU FT	2	2	4
6 ACT ALUM FLUORIDE REM, RFREQ 48	32.0 TO 753.0 CU FT	2	2	4
7 PACKAGE LIME SOFTENING,ONE STAGE	15000.0 TO 1000000.0 GPD	4	2	6
8 PACKAGE LIME SOFTENING,TWO STAGE	15000.0 TO 1000000.0 GPD	4	2	6
9 PCKG PRESSURE FILT,2 GPM/SF,1 BW	.3 TO 79.0 SQ FT	3	2	5
10 PCKG PRESSURE FILT,2 GPM/SF,2 BW	.3 TO 79.0 SQ FT	3	2	5
11 PCKG PRESSURE FILT,5 GPM/SF,1 BW	.3 TO 79.0 SQ FT	3	2	5
12 PCKG PRESSURE FILT,5 GPM/SF,2 BW	.3 TO 79.0 SQ FT	3	2	5
13 PCKG GRAVITY FILT,2 GPM/SF,1 BW	6.3 TO 225.0 SQ FT	1	2	3
14 PCKG GRAVITY FILT,2 GPM/SF,2 BW	6.3 TO 225.0 SQ FT	1	2	3
15 PCKG GRAVITY FILT,5 GPM/SF,1 BW	6.3 TO 225.0 SQ FT	1	2	3
16 PCKG GRAVITY FILT,5 GPM/SF,2 BW	6.3 TO 225.0 SQ FT	1	2	3
17 PCKG PRESSURE CARBON CONTACTORS	1.8 TO 785.0 CU FT	1	2	3
18 PCKG GRAVITY CARBON CONTACTORS	31.5 TO 1130.0 CU FT	1	2	3
19 REVERSE OSMOSIS, TDS 5000 MG/L	2500.0 TO 1000000.0 GPD	3	2	5
20 REVERSE OSMOSIS, TDS 8000 MG/L	2500.0 TO 1000000.0 GPD	3	2	5
21 REVERSE OSMOSIS, TDS 10000 MG/L	2500.0 TO 1000000.0 GPD	3	2	5
22 REVERSE OSMOSIS, LOW PRESSURE	2500.0 TO 1000000.0 GPD	3	2	5
23 GAS FEED CHLOR., TO 40 LB/DAY	1.0 TO 40.0 LB/DAY	1	1	3

TABLE 194 (Continued)

TREATMENT PROCESS	PARAMETER RANGE	NUMBER OF CHEMICALS	PROCESS TYPE	NO. DATA LINES
24 GAS FEED CHLOR., 40 TO 80 LB/DAY	40.0 TO 80.0 LB/DAY	1	1	3
25 HYPOCHLORITE SOL. CHLORINATION	1.0 TO 100.0 LB/DAY	1	1	3
26 ULTRAVIOLET LIGHT DISINFECTION	5760.0 TO 1010000.0 GPD	0	1	2
27 PACKAGE ULTRAFILTRATION PLANTS	30.0 TO 14300.0 SQ FT	0	1	2
28 COVERED SLOW SAND FILTERS	1080.0 TO 16000.0 SQ FT	0	1	2
29 UNCOVERED SLOW SAND FILTERS	1080.0 TO 16000.0 SQ FT	0	1	2
30 PACKAGE HIGH SERVICE PUMPING STA	43200.0 TO 2880000.0 GPD	0	1	2
31 PACKAGE RAW WATER PUMPING STA.	28800.0 TO 1010000.0 GPD	0	1	2
32 ELECTRODIALYSIS, TDS 1000 MG/L	1500.0 TO 1000000.0 GPD	2	2	4
33 ELECTRODIALYSIS, TDS 2000 MG/L	1500.0 TO 1000000.0 GPD	2	2	4
34 ELECTRODIALYSIS, TDS 3000 MG/L	1500.0 TO 1000000.0 GPD	2	2	4
35 EROSION FEED CHLOR., GRAVITY	.1 TO 6.0 LB/DAY	1	1	3
36 EROSION FEED CHLOR., VENTURI	.1 TO 6.0 LB/DAY	1	1	3
37 EROSION FEED CHLOR., CHEM PUMP	.1 TO 6.0 LB/DAY	1	1	3
38 CHLORINE DIOXIDE GEN. & FEED EQ.	.1 TO 43.8 LB/DAY	3	2	5
39 OZONE GENERATION,FEED-AIR,5 KWH	5.0 TO 110.0 LB/DAY	0	1	2
40 OZONE GENERATION,FEED-AIR,8 KWH	5.0 TO 110.0 LB/DAY	0	1	2
41 OZONE GENERATION,FEED-O2,3.5 KWH	10.0 TO 220.0 LB/DAY	0	1	2
42 OZONE CONTACTORS	2000.0 TO 15000.0 GAL	0	1	2
43 PACKAGE VACUUM DIATOMITE FILTERS	30.0 TO 720.0 SQ FT	2	2	4
44 PACKAGE PRESSURE DIATOMITE FILT.	19.2 TO 750.0 SQ FT	1	2	3
45 DIFFUSED AERATION, 2.6 SCFM, 7FT	200.0 TO 7000.0 GAL	0	1	2
46 DIFFUSED AERATION, 2.6 SCFM,12FT	400.0 TO 14000.0 GAL	0	1	2

TABLE 194. (Continued)

TREATMENT PROCESS	PARAMETER RANGE	NUMBER OF CHEMICALS	PROCESS TYPE	NO. DATA LINES
47 DIFFUSED AERATION, 5.3 SCFM, 7FT	200.0 TO 7000.0 GAL	0	1	2
48 DIFFUSED AERATION, 5.3 SCFM,12FT	400.0 TO 14000.0 GAL	0	1	2
49 DIFFUSED AERATION, 7.9 SCFM, 7FT	200.0 TO 7000.0 GAL	0	1	2
50 DIFFUSED AERATION, 7.9 SCFM,12FT	400.0 TO 14000.0 GAL	0	1	2
51 WATER WELLS, 250 FT DEPTH	144000.0 TO 1010000.0 GPD	0	1	2
52 WATER WELLS, 500 FT DEPTH	144000.0 TO 1010000.0 GPD	0	1	2
53 FILTER MEDIA, RAPID SAND	2.0 TO 350.0 SQ FT	0	1	2
54 FILTER MEDIA, DUAL MEDIA	2.0 TO 350.0 SQ FT	0	1	2
55 FILTER MEDIA, MIXED MEDIA	2.0 TO 350.0 SQ FT	0	1	2
56 MULTI-TECH SYSTEM	65000.0 TO 1100000.0 GPD	2	2	4
57 MULTI-TECH SYSTEM PLUS CARBON	65000.0 TO 1100000.0 GPD	3	2	5
58 BELOW GROUND CONCRETE CLEARWELL	5000.0 TO 500000.0 GAL	0	1	2
59 GROUND-LEVEL STEEL CLEARWELLS	1000.0 TO 1000000.0 GAL	0	1	2
60 PACKAGE FLOCCULATOR/CLARIFIER	70.0 TO 740.0 SQ FT	2	2	4
61 CONTACT BASINS	1200.0 TO 42000.0 GAL	0	1	2
62 PELLET FEED CHLORINATORS	.1 TO 13.0 LB/DAY	1	1	3
63 SLUDGE DISPOSAL TO SANIT. SEWERS	1000.0 TO 100000.0 MG/L	0	11	3
64 ON SITE HYPOCHLORITE GENERATION	20.0 TO 100.0 LB/DAY	1	2	3
65 CONVEN. PCKG COMPL,2 GPM/SF,1 BW	2.0 TO 150.0 SQ FT	2	2	4
66 CONVEN. PCKG COMP.,2 GPM/ST,2 BW	2.0 TO 150.0 SQ FT	2	2	4
67 CONVEN. PCKG COMPL,5 GPM/SF,1 BW	2.0 TO 150.0 SQ FT	2	2	4
68 CONVEN. PCKG COMPL,5 GPM/SF,2 BW	2.0 TO 150.0 SQ FT	2	2	4
69 NEPTUNE MICROFLOC TRIDENT, 1 BW	252000.0 TO 1010000.0 GPD	3	2	5

TABLE 194. (Continued)

TREATMENT PROCESS	PARAMETER RANGE				NUMBER OF CHEMICALS	PROCESS TYPE	NO. DATA LINES
70 NEPTUNE MICROFLOC TRIDENT, 2 BW	252000.0	TO	1010000.0	GPD	3	2	5
71 BASIC POLYMER FEED, ONE TANK	.6	TO	10.4	LB/DAY	1	1	3
72 BASIC POLYMER FEED, TWO TANKS	.6	TO	10.4	LB/DAY	1	1	3
73 AUTOMATIC POLYMER FEED SYSTEM	.5	TO	10.0	LB/DAY	1	1	3
74 SAND DRYING BEDS,5 CLEANINGS/YR	200.0	TO	2000.0	SQ FT	0	1	2
75 SAND DRYING BEDS,8 CLEANINGS/YR	200.0	TO	2000.0	SQ FT	0	1	2
76 SAND DRYING BEDS,15 CLEANINGS/YR	200.0	TO	2000.0	SQ FT	0	1	2
77 BASIC CHEMICAL FEED,ALL BUT LIME	10.0	TO	1000.0	LB/DAY	1	1	3
78 BASIC CHEMICAL FEED, HYDR LIME	10.0	TO	1000.0	LB/DAY	1	1	3
79 DRY CHEMICAL FEEDER SYSTEM	1.7	TO	33.0	CF/DAY	1	1	3
O&M:	51.5	TO	999.9	LB/DAY			
80 SULFURIC ACID FEED SYSTEMS	.8	TO	834.0	LB/DAY	1	1	3
81 SODIUM HYDROXIDE FEED SYSTEMS	.8	TO	834.0	LB/DAY	1	1	3
82 POTASSIUM PERMANGANATE FEED SYS.	5.0	TO	250.0	LB/DAY	1	1	3
83 FERRIC CHLORIDE FEED SYSTEMS	1.0	TO	750.0	LB/DAY	1	1	3
84 POWDERED ACT CARBON FEED, SLURRY	50.0	TO	250.0	LB/DAY	1	1	3
85 POWDERED ACT CARBON FEED, DRY	50.0	TO	250.0	LB/DAY	1	1	3
86 SLUDGE DEWATERING LAGOONS	2500.0	TO	147000.0	CU FT	0	1	2
O&M:	340.0	TO	19992.0	CF/YR			
87 CATION EXCHNG SOFTNG,1 DAY RFREQ	3.0	TO	520.0	CU FT	1	2	3
88 CATION EXCHNG SOFTNG,2 DAY RFREQ	3.0	TO	520.0	CU FT	1	2	3
89 CATION EXCHNG SOFTNG,4 DAY RFREQ	3.0	TO	520.0	CU FT	1	2	3
90 ANION EXCHNG NO3 REM,2/DAY RFREQ	4.0	TO	520.0	CU FT	1	2	3
91 ANION EXCHNG NO3 REM,DAILY RFREQ	4.0	TO	520.0	CU FT	1	2	3

TABLE 194. (Continued)

TREATMENT PROCESS	PARAMETER RANGE				NUMBER OF CHEMICALS	PROCESS TYPE	NO. DATA LINES
92 ANION EXCHNG NO3 REM,2 DAY RFREQ	4.0	TO	520.0	CU FT	1	2	3
93 COUNTERCUR PACKED TOWER AER,10:1	12.6	TO	453.0	CU FT	0	1	2
O&M:	27846.0	TO	1001130.0	GPD			
94 COUNTERCUR PACKED TOWER AER,20:1	12.6	TO	453.0	CU FT	0	1	2
O&M:	27846.0	TO	1001130.0	GPD			
95 SPRAY AERATION SYSTEMS	28000.0	TO	1010000.0	GPD	0	1	2
96 CASCADE TRAY AERATORS	65000.0	TO	1000000.0	GPD	0	1	2
97 BRINE EVAP LAGOONS, NO LINER	3500.0	TO	653000.0	SQ FT	0	1	2
98 BRINE EVAP LAGOONS, WITH LINER	3500.0	TO	653000.0	SQ FT	0	1	2
99 LIQUID SLUDGE HAUL,8 MPG,20 MPH	1600.0	TO	4000.0	GAL	0	12	4
O&M:	4000.0	TO	10000.0	ML/YR			
100 DEWATERED SLUDGE HAUL,8MPG,20MPH	100.0	TO	10000.0	CU YD	0	12	4
O&M:	100.0	TO	10000.0	ML/YR			

TABLE 195. TREATMENT PROCESSES THAT USE CHEMICALS AND CHEMICALS USED

TREATMENT PROCESS	CHEMICALS USED
1 ACT ALUM FLUORIDE REM, RFREQ 4.5	SODIUM HYDROXIDE, SULFURIC ACID
2 ACT ALUM FLUORIDE REM, RFREQ 8	SODIUM HYDROXIDE, SULFURIC ACID
3 ACT ALUM FLUORIDE REM, RFREQ 12	SODIUM HYDROXIDE, SULFURIC ACID
4 ACT ALUM FLUORIDE REM, RFREQ 19	SODIUM HYDROXIDE, SULFURIC ACID
5 ACT ALUM FLUORIDE REM, RFREQ 33	SODIUM HYDROXIDE, SULFURIC ACID
6 ACT ALUM FLUORIDE REM, RFREQ 48	SODIUM HYDROXIDE, SULFURIC ACID
7 PACKAGE LIME SOFTENING,ONE STAGE	LIME, SODA ASH, CARBON DIOXIDE GAS, SULFURIC ACID
8 PACKAGE LIME SOFTENING,TWO STAGE	LIME, SODA ASH, CARBON DIOXIDE GAS, SULFURIC ACID
9 PCKG PRESSURE FILT,2 GPM/SF,1 BW	SODIUM HYPOCHLORITE, POLYMER, POTASSIUM PERMNGNATE
10 PCKG PRESSURE FILT,2 GPM/SF,2 BW	SODIUM HYPOCHLORITE, POLYMER, POTASSIUM PERMNGNATE
11 PCKG PRESSURE FILT,5 GPM/SF,1 BW	SODIUM HYPOCHLORITE, POLYMER, POTASSIUM PERMNGNATE
12 PCKG PRESSURE FILT,5 GPM/SF,2 BW	SODIUM HYPOCHLORITE, POLYMER, POTASSIUM PERMNGNATE
13 PCKG GRAVITY FILT,2 GPM/SF,1 BW	POLYMER
14 PCKG GRAVITY FILT,2 GPM/SF,2 BW	POLYMER
15 PCKG GRAVITY FILT,5 GPM/SF,1 BW	POLYMER
16 PCKG GRAVITY FILT,5 GPM/SF,2 BW	POLYMER
17 PCKG PRESSURE CARBON CONTACTORS	CARBON
18 PCKG GRAVITY CARBON CONTACTORS	CARBON
19 REVERSE OSMOSIS, TDS 5000 MG/L	SULF. ACID, SOD. HYPOCHLORITE, POTASSIUM PERMNGNTE
20 REVERSE OSMOSIS, TDS 8000 MG/L	SULF. ACID, SOD. HYPOCHLORITE, POTASSIUM PERMNGNTE
21 REVERSE OSMOSIS, TDS 10000 MG/L	SULF. ACID, SOD. HYPOCHLORITE, POTASSIUM PERMNGNTE
22 REVERSE OSMOSIS, LOW PRESSURE	SULF. ACID, SOD. HYPOCHLORITE, POTASSIUM PERMNGNTE
23 GAS FEED CHLOR., TO 40 LB/DAY	CHLORINE GAS
24 GAS FEED CHLOR., 40 TO 80 LB/DAY	CHLORINE GAS

TABLE 195. (Continued)

TREATMENT PROCESS	CHEMICALS USED
25 HYPOCHLORITE SOL. CHLORINATION	SODIUM HYPOCHLORITE
32 ELECTRODIALYSIS, TDS 1000 MG/L	HYDROCHLORIC ACID,SODIUM HYDROXIDE
33 ELECTRODIALYSIS, TDS 2000 MG/L	HYDROCHLORIC ACID,SODIUM HYDROXIDE
34 ELECTRODIALYSIS, TDS 3000 MG/L	HYDROCHLORIC ACID,SODIUM HYDROXIDE
35 EROSION FEED CHLOR., GRAVITY	CALCIUM HYPOCHLORITE TABLETS
36 EROSION FEED CHLOR., VENTURI	CALCIUM HYPOCHLORITE TABLETS
37 EROSION FEED CHLOR., CHEM PUMP	CALCIUM HYPOCHLORITE TABLETS
38 CHLORINE DIOXIDE GEN. & FEED EQ.	CHLORINE, SODIUM CHLORITE, HYDROCHLORIC ACID
43 PACKAGE VACUUM DIATOMITE FILTERS	DIATOMACEOUS EARTH, POLYMER
44 PACKAGE PRESSURE DIATOMITE FILT.	DIATOMACEOUS EARTH
56 MULTI-TECH SYSTEM	ALUM, POLYMER
57 MULTI-TECH SYSTEM PLUS CARBON	ALUM, POLYMER, CARBON
60 PACKAGE FLOCCULATOR/CLARIFIER	ALUM, POLYMER
62 PELLET FEED CHLORINATORS	CALCIUM HYPOCHLORITE
64 ON SITE HYPOCHLORITE GENERATION	SALT
65 CONVEN. PCKG COMPL,2 GPM/SF,1 BW	ALUM, POLYMER
66 CONVEN. PCKG COMP.,2 GPM/ST,2 BW	ALUM, POLYMER
67 CONVEN. PCKG COMPL,5 GPM/SF,1 BW	ALUM, POLYMER
68 CONVEN. PCKG COMPL,5 GPM/SF,2 BW	ALUM, POLYMER
69 NEPTUNE MICROFLOC TRIDENT, 1 BW	ALUM, POLYMER, SODIUM HYPOCHLORITE
70 NEPTUNE MICROFLOC TRIDENT, 2 BW	ALUM, POLYMER, SODIUM HYPOCHLORITE
71 BASIC POLYMER FEED, ONE TANK	POLYMER
72 BASIC POLYMER FEED, TWO TANKS	POLYMER
73 AUTOMATIC POLYMER FEED SYSTEM	POLYMER

TABLE 195. (Continued)

TREATMENT PROCESS	CHEMICALS USED
77 BASIC CHEMICAL FEED,ALL BUT LIME	ALL CHEMICALS BUT LIME
78 BASIC CHEMICAL FEED, HYDR LIME	HYDRATED LIME
79 DRY CHEMICAL FEEDER SYSTEM	ANY COMMON DRY CHEMICALS
80 SULFURIC ACID FEED SYSTEMS	SULFURIC ACID
81 SODIUM HYDROXIDE FEED SYSTEMS	SODIUM HYDROXIDE
82 POTASSIUM PERMANGANATE FEED SYS.	POTASSIUM PERMANGANATE
83 FERRIC CHLORIDE FEED SYSTEMS	FERRIC CHLORIDE
84 POWDERED ACT CARBON FEED, SLURRY	POWDERED ACTIVATED CARBON
85 POWDERED ACT CARBON FEED, DRY	POWDERED ACTIVATED CARBON
87 CATION EXCHNG SOFTNG,1 DAY RFREQ	SALT
88 CATION EXCHNG SOFTNG,2 DAY RFREQ	SALT
89 CATION EXCHNG SOFTNG,4 DAY RFREQ	SALT
90 ANION EXCHNG NO3 REM,2/DAY RFREQ	SALT
91 ANION EXCHNG NO3 REM,DAILY RFREQ	SALT
92 ANION EXCHNG NO3 REM,2 DAY RFREQ	SALT

The last line in the PROCES.DAT file is the last line of the last segment of data. A ZERO line must not be placed at the end of the file. A ZERO line is only placed between segments.

Process Types and Data Input

The various process types require two to seven lines for data input. The first two lines of data for all process types are the same. Data line format and content are explained in the following discussion.

Type 1 Process Data Input--

Line 1--The first line of data contains the following information starting in column 1: The line number (the integer 1) followed by a comma in column 2, the process number (integer) from Table 194 followed immediately by a comma, and finally, the process name.

Examples:

```
Line 1:  1,23,GAS FEED CHLOR., TO 40 LB/DAY
Line 1:  1,30,PACKAGE HIGH SERVICE PUMPING STA
Line 1:  1,59,GROUND-LEVEL STEEL CLEARWELLS
```

The commas are necessary to separate numbers and must not be omitted. The process name is optional, but, it is a useful identifier for the user when reviewing the PROCES.DAT file later. The comma preceding the process name is not optional.

Line 2--The second line of data contains the following information starting in column 1: The line number (the integer 2) followed by a comma in column 2, the plant design flow in mgd (floating point) followed by a comma, the plant actual flow in mgd (floating point) followed by a comma, the process design parameter (floating point) followed by a comma, and the process operating parameter (floating point).

Examples: Using the same three examples as used above for Line 1, assume the following:

Example 1: Plant Design Flow = .75 mgd
Plant Operating Flow = .53 mgd
Chlorinator Design Feed = 18.8 lb/day
Chlorinator Operating Feed = 6.6 lb/day
Line 2: 2,.75,.53,18.8,6.6

Example 2: Plant Design Flow = 1.0 mgd
Plant Operating Flow = 0.7 mgd
Design Raw Water Pumping Rate = 1,000,000 gal/day
Operating Raw Water Pumping Rate = 700,000 gal/day
2,1.0,0.7,1000000.,700000.

Example 3: Plant Design Flow = 0.5 mgd
Plant Actual Flow = 0.35 mgd
Clearwell Design Storage,125000 gal
Clearwell Operating Storage,125000 gal
Line 2: 2,0.5,0.35,125000.,125000.

The process design and operating parameters have the units specified in Tables 194 and 196. The process design parameter is used to calculate construction costs, and building energy, and the operating parameter is used to determine operation and maintenance costs (except building energy). In some cases, these parameters have different units and/or ranges. In Table 194, for example, process 99 (LIQUID SLUDGE HAUL,8 MPG,20 MPH) has the unit gal for the design parameter and miles/yr for the operating parameter. All values are floating point (except the line number) and are separated by a comma. Notice that for some processes such as chemical feed and pumping, the numerical values of the design and operating parameters may be different, since the design parameter indicates capacity, and these processes generally do not operate at capacity. For other processes, such as clearwell storage, the design and operating parameters are usually identical.

Lines 3 and 4--The number of lines for a type 1 process is equal to 2 plus the number of chemicals. For example, process number 80, SULFURIC ACID FEED SYSTEMS, requires 2 + 1 = 3 lines. Process 30 (PACKAGE HIGH SERVICE PUMPING STA) requires 2 + 0 = 2 lines.

If a third or fourth line of data is required, it contains the following information: The number of the line (the integer 3 or 4) followed by a comma, the cost of the chemical(s) used in the process in dollars/ton (floating point) followed by a comma, and the name of the chemical used in the process (up to 24 characters). For most processes, the chemical(s) used will be obvious. For example, process 23 (GAS FEED CHLOR., TO 40 LB/DAY) uses gaseous chlorine. For convenience, however, the processes that use chemicals and the names of the chemicals are shown in Table 195.

Examples: Chlorine = $300/ton

Line 3: 3,300.00,CHLORINE

Since the 24 characters immediately following the second comma are copied on the printout, other useful information may be included. For example, chlorine dosage could be included:

Line 3: 3,300.00,CHLORINE (DOSE = 2 mg/L)

Any characters following the 24th character will be ignored.

Completed Examples--The following three examples show all lines necessary for data input of the processes shown. All data begin in column 1.

Line 1: 1,23,GAS FEED CHLOR., TO 40 LB/DAY
Line 2: 2,.75,.53,18.8,6.6
Line 3: 3,300.00,CHLORINE (DOSE = 2 mg/L)

TABLE 196. PROCESS PARAMETER UNITS

TREATMENT PROCESS	UNITS
1 ACT ALUM FLUORIDE REM, RFREQ 4.5	CU FT OF CONTACTOR VOLUME
2 ACT ALUM FLUORIDE REM, RFREQ 8	CU FT OF CONTACTOR VOLUME
3 ACT ALUM FLUORIDE REM, RFREQ 12	CU FT OF CONTACTOR VOLUME
4 ACT ALUM FLUORIDE REM, RFREQ 19	CU FT OF CONTACTOR VOLUME
5 ACT ALUM FLUORIDE REM, RFREQ 33	CU FT OF CONTACTOR VOLUME
6 ACT ALUM FLUORIDE REM, RFREQ 48	CU FT OF CONTACTOR VOLUME
7 PACKAGE LIME SOFTENING,ONE STAGE	GPD OF PLANT CAPACITY
8 PACKAGE LIME SOFTENING,TWO STAGE	GPD OF PLANT CAPACITY
9 PCKG PRESSURE FILT,2 GPM/SF,1 BW	SQ FT OF FILTER AREA
10 PCKG PRESSURE FILT,2 GPM/SF,2 BW	SQ FT OF FILTER AREA
11 PCKG PRESSURE FILT,5 GPM/SF,1 BW	SQ FT OF FILTER AREA
12 PCKG PRESSURE FILT,5 GPM/SF,2 BW	SQ FT OF FILTER AREA
13 PCKG GRAVITY FILT,2 GPM/SF,1 BW	SQ FT OF FILTER AREA
14 PCKG GRAVITY FILT,2 GPM/SF,2 BW	SQ FT OF FILTER AREA
15 PCKG GRAVITY FILT,5 GPM/SF,1 BW	SQ FT OF FILTER AREA
16 PCKG GRAVITY FILT,5 GPM/SF,2 BW	SQ FT OF FILTER AREA
17 PCKG PRESSURE CARBON CONTACTORS	CU FT OF CARBON CONTACTOR VOLUME
18 PCKG GRAVITY CARBON CONTACTORS	CU FT OF CARBON CONTACTOR VOLUME
19 REVERSE OSMOSIS, TDS 5000 MG/L	GPD OF PLANT CAPACITY
20 REVERSE OSMOSIS, TDS 8000 MG/L	GPD OF PLANT CAPACITY
21 REVERSE OSMOSIS, TDS 10000 MG/L	GPD OF PLANT CAPACITY
22 REVERSE OSMOSIS, LOW PRESSURE	GPD OF PLANT CAPACITY
23 GAS FEED CHLOR., TO 40 LB/DAY	LB/DAY OF CHLORINE FEED CAPACITY
24 GAS FEED CHLOR., 40 TO 80 LB/DAY	LB/DAY OF CHLORINE FEED CAPACITY

TABLE 196. (Continued)

TREATMENT PROCESS	UNITS
25 HYPOCHLORITE SOL. CHLORINATION	LB/DAY OF AVAILABLE CHLORINE
26 ULTRAVIOLET LIGHT DISINFECTION	GPD OF PLANT CAPACITY
27 PACKAGE ULTRAFILTRATION PLANTS	SQ FT OF FILTER AREA
28 COVERED SLOW SAND FILTERS	SQ FT OF TOTAL FILTER AREA
29 UNCOVERED SLOW SAND FILTERS	SQ FT OF TOTAL FILTER AREA
30 PACKAGE HIGH SERVICE PUMPING STA	GPD OF PUMPING CAPACITY
31 PACKAGE RAW WATER PUMPING STA.	GPD OF PUMPING CAPACITY
32 ELECTRODIALYSIS, TDS 1000 MG/L	GPD OF PLANT CAPACITY
33 ELECTRODIALYSIS, TDS 2000 MG/L	GPD OF PLANT CAPACITY
34 ELECTRODIALYSIS, TDS 3000 MG/L	GPD OF PLANT CAPACITY
35 EROSION FEED CHLOR., GRAVITY	LB/DAY OF MAXIMUM FEED RATE
36 EROSION FEED CHLOR., VENTURI	LB/DAY OF MAXIMUM FEED RATE
37 EROSION FEED CHLOR., CHEM PUMP	LB/DAY OF MAXIMUM FEED RATE
38 CHLORINE DIOXIDE GEN. & FEED EQ.	LB/DAY OF MAXIMUM FEED RATE
39 OZONE GENERATION,FEED-AIR,5 KWH	LB/DAY OF MAXIMUM FEED RATE
40 OZONE GENERATION,FEED-AIR,8 KWH	LB/DAY OF MAXIMUM FEED RATE
41 OZONE GENERATION,FEED-02,3.5 KWH	LB/DAY OF MAXIMUM FEED RATE
42 OZONE CONTACTORS	GAL OF CONTACTOR VOLUME
43 PACKAGE VACUUM DIATOMITE FILTERS	SQ FT OF FILTER AREA
44 PACKAGE PRESSURE DIATOMITE FILT.	SQ FT OF FILTER AREA
45 DIFFUSED AERATION, 2.6 SCFM, 7FT	GAL OF TANK VOLUME
46 DIFFUSED AERATION, 2.6 SCFM,12FT	GAL OF TANK VOLUME
47 DIFFUSED AERATION, 5.3 SCFM, 7FT	GAL OF TANK VOLUME
48 DIFFUSED AERATION, 5.3 SCFM,12FT	GAL OF TANK VOLUME

TABLE 196. (Continued)

TREATMENT PROCESS	UNITS
49 DIFFUSED AERATION, 7.9 SCFM, 7FT	GAL OF TANK VOLUME
50 DIFFUSED AERATION, 7.9 SCFM,12FT	GAL OF TANK VOLUME
51 WATER WELLS, 250 FT DEPTH	GPD OF WELL CAPACITY
52 WATER WELLS, 500 FT DEPTH	GPD OF WELL CAPACITY
53 FILTER MEDIA, RAPID SAND	SQ FT OF FILTER AREA
54 FILTER MEDIA, DUAL MEDIA	SQ FT OF FILTER AREA
55 FILTER MEDIA, MIXED MEDIA	SQ FT OF FILTER AREA
56 MULTI-TECH SYSTEM	GPD OF PLANT CAPACITY
57 MULTI-TECH SYSTEM PLUS CARBON	GPD OF PLANT CAPACITY
58 BELOW GROUND CONCRETE CLEARWELL	GAL OF CLEARWELL CAPACITY
59 GROUND-LEVEL STEEL CLEARWELLS	GAL OF CLEARWELL CAPACITY
60 PACKAGE FLOCCULATOR/CLARIFIER	SQ FT OF SETTLING SURFACE AREA
61 CONTACT BASINS	GAL OF BASIN VOLUME
62 PELLET FEED CHLORINATORS	LB/DAY OF MAXIMUM FEED RATE
63 SLUDGE DISPOSAL TO SANIT. SEWERS	MG/L OF SUSPENDED SOLIDS CONCENTRATION
64 ON SITE HYPOCHLORITE GENERATION	LB/DAY OF MAXIMUM GENERATION RATE
65 CONVEN. PCKG COMPL,2 GPM/SF,1 BW	SQ FT OF FILTER AREA
66 CONVEN. PCKG COMP.,2 GPM/ST,2 BW	SQ FT OF FILTER AREA
67 CONVEN. PCKG COMPL,5 GPM/SF,1 BW	SQ FT OF FILTER AREA
68 CONVEN. PCKG COMPL,5 GPM/SF,2 BW	SQ FT OF FILTER AREA
69 NEPTUNE MICROFLOC TRIDENT, 1 BW	GPD OF PLANT CAPACITY
70 NEPTUNE MICROFLOC TRIDENT, 2 BW	GPD OF PLANT CAPACITY
71 BASIC POLYMER FEED, ONE TANK	LB/DAY OF MAXIMUM FEED RATE
72 BASIC POLYMER FEED, TWO TANKS	LB/DAY OF MAXIMUM FEED RATE

TABLE 196. (Continued)

TREATMENT PROCESS	UNITS
73 AUTOMATIC POLYMER FEED SYSTEM	LB/DAY OF MAXIMUM FEED RATE
74 SAND DRYING BEDS,5 CLEANINGS/YR	SQ FT OF TOTAL BED AREA
75 SAND DRYING BEDS,8 CLEANINGS/YR	SQ FT OF TOTAL BED AREA
76 SAND DRYING BEDS,15 CLEANINGS/YR	SQ FT OF TOTAL BED AREA
77 BASIC CHEMICAL FEED,ALL BUT LIME	LB/DAY OF MAXIMUM FEED RATE
78 BASIC CHEMICAL FEED, HYDR LIME	LB/DAY OF MAXIMUM FEED RATE
79 DRY CHEMICAL FEEDER SYSTEM	CF/DAY OF MAXIMUM FEED RATE (CU FT)
O&M:	LB/DAY OF AVERAGE RATE
80 SULFURIC ACID FEED SYSTEMS	LB/DAY OF MAXIMUM FEED RATE
81 SODIUM HYDROXIDE FEED SYSTEMS	LB/DAY OF MAXIMUM FEED RATE
82 POTASSIUM PERMANGANATE FEED SYS.	LB/DAY OF MAXIMUM FEED RATE
83 FERRIC CHLORIDE FEED SYSTEMS	LB/DAY OF MAXIMUM FEED RATE
84 POWDERED ACT CARBON FEED, SLURRY	LB/DAY OF MAXIMUM FEED RATE
85 POWDERED ACT CARBON FEED, DRY	LB/DAY OF MAXIMUM FEED RATE
86 SLUDGE DEWATERING LAGOONS	CU FT OF EFFECTIVE STORAGE VOLUME
O&M:	CF/YR OF SLUDGE REMOVED
87 CATION EXCHNG SOFTNG,1 DAY RFREQ	CU FT OF TOTAL RESIN VOLUME
88 CATION EXCHNG SOFTNG,2 DAY RFREQ	CU FT OF TOTAL RESIN VOLUME
89 CATION EXCHNG SOFTNG,4 DAY RFREQ	CU FT OF TOTAL RESIN VOLUME
90 ANION EXCHNG NO3 REM,2/DAY RFREQ	CU FT OF TOTAL RESIN VOLUME
91 ANION EXCHNG NO3 REM,DAILY RFREQ	CU FT OF TOTAL RESIN VOLUME
92 ANION EXCHNG NO3 REM,2 DAY RFREQ	CU FT OF TOTAL RESIN VOLUME
93 COUNTERCUR PACKED TOWER AER,10:1	CU FT OF TOWER VOLUME
O&M:	GPD OF AVERAGE FLOW
94 COUNTERCUR PACKED TOWER AER,20:1	CU FT OF TOWER VOLUME
O&M:	GPD OF AVERAGE FLOW

TABLE 196. (Continued)

TREATMENT PROCESS	UNITS
95 SPRAY AERATION SYSTEMS	GPD OF PLANT CAPACITY
96 CASCADE TRAY AERATORS	GPD OF PLANT CAPACITY
97 BRINE EVAP LAGOONS, NO LINER	SQ FT OF LAGOON SURFACE AREA
98 BRINE EVAP LAGOONS, WITH LINER	SQ FT OF LAGOON SURFACE AREA
99 LIQUID SLUDGE HAUL,8 MPG,20 MPH	GAL OF TRUCK CAPACITY
O&M:	ML/YR OF (MILES) DRIVEN
100 DEWATERED SLUDGE HAUL,8MPG,20MPH	CU YD OF TRUCK CAPACITY
O&M:	ML/YR OF (MILES) DRIVEN

Line 1: 1,30,PACKAGE HIGH SERVICE PUMPING STA
Line 2: 2,.75,.53,750000.,530000.

Line 1: 1,59,GROUND-LEVEL STEEL CLEARWELLS
Line 2: 2,.5,.35,125000.,125000.

Type 2 Process Data Input--

The total number of data lines required for a type 2 proccess is 2 + number of chemicals. The first two lines of data are identical in format and content to a type 1 process. The remaining lines contain chemical cost and chemical feed information. For example, process 22 (REVERSE OSMOSIS-LOW PRESSURE) may use up to 3 chemicals: sulfuric acid, sodium hexametaphosphate, and chlorine. This process requires 2 + 3 = 5 lines of data with the following information: The line number (integer) followed by a comma, the cost of the chemical in $/ton (floating point) followed by a comma, the actual (not design) feed rate in lb/day for the chemical (floating point) followed by a comma, and the name of the chemical (not to exceed 24 characters). The chemicals can be input in any order. If one or more of the chemicals is not used, an input of zeros for the chemical cost and the chemical feed rate will cause no information to be printed on the output for that chemical. To illustrate, the 5 data lines for process 22 (REVERSE OSMOSIS-LOW PRESSURE) may be constructed as follows:

Line 1: 1,22,REVERSE OSMOSIS-LOW PRESSURE
Line 2: 2,1.0,0.7,1000000.,700000.
Line 3: 3,80.0,116.8,SULFURIC ACID, 20 MG/L
Line 4: 4,1000.0,29.2,SODIUM HEXA PO3,5 MG/L
Line 5: 5,300.0,11.7,CHLORINE,2 MG/L

Line 1: 1,22,REVERSE OSMOSIS-LOW PRESSURE
Line 2: 2,1.0,0.7,1000000.,700000.
Line 3: 3,1000.0,29.2,SODIUM HEXA PO3,5 MG/L
Line 4: 4,80.0,58.4,SULFURIC ACID,10 MG/L
Line 5: 5,0.0,0.0

Line 1: 1,22,REVERSE OSMOSIS-LOW PRESSURE
Line 2: 2,1.0,0.7,1000000.,700000.
Line 3: 3,0.0,0.0
Line 4: 4,0.0,0.0
Line 5: 5,0.0,0.0

Example 1, above, indicates the following:

Line 3: $80.00/ton cost and 116.8 lb/day feed rate for sulfuric acid at a dose of 20 mg/L

Line 4: $1000.00/ton and 29.2 lb/day feed rate for sodium hexametaphosphate at dose of 5 mg/L

Line 5: $300.00/ton and 11.7 lb/day feed rate for chlorine at 2 mg/L

Example 2, above, indicates the following:

Card 3: $1000.00/ton and 29.2 lb/day feed rate for sodium hexametaphosphate at a 5 mg/L dose
Card 4: $80.00/ton and 58.4 lb/day feed rate for sulfuric acid at a 10 mg/L dose
Card 5: No other chemicals used

Example 3, above, indicates that no chemicals were used in this process since lines 3 to 5 contained zeros for the chemicals costs and feed rates.

Types 3 Through 10--

Not applicable to the processes included in this report.

Type 11 Process Data Input--

The total number of data lines for type 11 is 3 + number of chemicals = 3 + 0 = 3. The first two data lines are identical in format and content to the first two data lines of type 1. The third data line for process 11 contains the integer 3 followed by a comma, the liquid sludge flow rate in gallons/day (floating point) followed by a comma, and the abbreviation gpd. The abbreviation gpd is optional, but the preceding comma is not.

Example:

```
Line 1:     1,63,SLUDGE DISPOSAL TO SANIT. SEWERS
Line 2:     2,.1,.1,2000.,2000.
Line 3:     3,10000.0,GPD
```

This example is for sludge disposal to a sanitary sewer, at a sludge concentration of 2,000 mg/L and a sludge flow of 2.64 m^3/d (10,000 gpd).

Type 12 Process Data Input--

The total number of lines for type 12 is 4 + number of chemicals = 4 + 0 = 4. The first two data lines are identical in format and content to the first two data lines of type 1. The third data line indicates the number of trucks required for sludge hauling. The fourth data line indicates percent usage of the truck by the treatment plant and contains the integer 4 followed by a comma, the percent ownership (floating point) followed by a comma, and the optional words % USAGE. The comma preceding % USAGE is not optional.

Example:

```
Line 1:     1,99,LIQUID SLUDGE HAUL, 8 MPG, 20 MPH
Line 2:     2,.5,.5,2000.,500.
Line 3:     3,1,TRUCK
Line 4:     4,50,% USAGE
```

It is important to note that the % USAGE reduces each component of cost. In this example, the construction cost and O&M would all be reduced by 50%. The number of units multiplies each component of cost. Therefore, if one entered 2 trucks at 50% USAGE the cost would be identical to 1 truck at 100% USAGE.

PROGRAM OUTPUT

Detailed or Summary

Program output is controlled by both the COST.DAT file and the PROCES.DAT file. The main option available to the user is determined in line 28 of the COST.DAT file. The two options available are the DETAILED or SUMMARY printout. Sample printouts for the summary printout are presented in Tables 197, 199 and 201. If the user chooses the DETAILED printout, he gets all the information contained in the SUMMARY plus a detailed cost breakdown for each process.

Repetitive Output

Program output is also controlled, in part, by the way in which the COST.DAT and PROCES.DAT files are constructed. In the COST.DAT File Construction discussion, it was shown that two additional lines of data could be added (lines 29 and 30) to the file to cause the program to be rerun. Line 29 designates which cost factor is to be changed during the rerun, and line 30 contains the values to be used during the rerun. In other words, if lines 29 and 30 were added to the COST.DAT file with the following information, the program

```
Line 29:    8,2
Line 30:    0.05,0.10
```

would be rerun twice using the existing PROCES.DAT file and the new values, 0.05 and 0.10, of cost factor number 8, ELECTRICITY, $/kwh. This has the same effect as running the program three times, and three complete program output listings will be generated: One complete output computing costs with the original cost of electricity, one complete output computing costs with electricity at $0.05/kwh, and one complete output computing costs with electricity at $0.10/kwh.

In the PROCES.DAT File Construction discussion, it was shown that data were input or assembled as segments, with a segment representing costs for one treatment plant. A complete program output includes computed costs listed separately for each data segment, with a listing of the COST.DAT file following the output for the final data segment. Therefore, if the PROCES.DAT file were constructed with five data segments and the COST.DAT file contained lines of 29 and 30, as shown above, the printout generated by the program would consist of:

1st data segment cost information
2nd data segment cost information
3rd data segment cost information
4th data segment cost information
5th data segment cost information
Listing of COST.DAT values used

1st data segment cost information
.
.
.

5th data segment cost information
Listing of COST.DAT values used (as above except electricity = $0.05/kwh)

1st data segment cost information
.
.
.
5th data segment cost information
Listing of COST.DAT values used (as above except electricity = $0.10/kwh)

Cost Extrapolation for Out-of-Range Inputs

Table 194 lists the processes for which costs are available and the design and operating parameter ranges over which these costs are valid. If the user attempts to obtain costs for process parameters outside the valid range, the program will extrapolate the stored costs and notify the user of this condition on the printout. The extrapolation is accomplished by evaluating the following equation for y after first computing the constants C_1 and C_2 from stored cost data:

$$\ln y = C_1 + C_2 \ln x$$

Where x is the input process parameter (out of range) and y is the extrapolated cost at x.

When plotted on log-log paper, this results in a linear extrapolation of the cost curve. A sample printout of extrapolated costs is shown in Table 202.

EXAMPLES

The following examples have been constructed to demonstrate the summary output. Each example includes a copy of the PROCESS.DAT file and the summary program output. The COST.DAT file for each of these examples is the same as Table 191, with the exception of lines 29 and 30.

Example 1 - Conventional Package Complete Treatment

This is a 1893 m^3/d (0.5 mgd) conventional package complete water treatment plant, operating at a flow rate of 1325 m^3/d (0.35 mgd), which is 70% of design capacity. In addition to the treatment plant, which includes alum and polymer feed, other processes included are raw and product water pumping, gas chlorine feed facilities, a ground-level steel clearwell, and liquid sludge disposal to a sanitary sewer. Alum and polymer feed rates are 20 mg/L and 0.2 mg/L respectively, and the chlorine feed rate is 1.5 mg/L. Table 197 presents the PROCESS.DAT file for this example, and Table 198 presents the summary program output.

TABLE 197. PROCES.DAT FILE FOR EXAMPLE 1, CONVENTIONAL PACKAGE COMPLETE TREATMENT PLANT

```
ACRES=0.6
1,31,PACKAGE RAW WATER PUMPING STA
2,.5,.35,720000.,350,000.
1,68,CONVEN. PCKG COMPL,5 GPM/SF,2 BW
2,.5,.35,87.,60.
3,150.0,57.6,ALUM
4,4000.0,0.576,POLYMER
1,23,GAS FEED CHLOR., TO 40 LB/DAY
2,.5,.35,12.5,4.32
3,300.0,CHLORINE GAS
1,59,GROUND-LEVEL STEEL CLEARWELLS
2,.5,.35,125000.,125000.
1,30,PACKAGE HIGH SERVICE PUMPING STA
2,.5,.35,720000.,350,000.
1,63,SLUDGE DISPOSAL TO SANIT. SEWERS
2,.5,.35,16800.,16800.
3,5,000.,GPD
```

Example 2 - Reverse Osmosis

Example 2 is a 3785 m^3/d (1.0 mgd) reverse osmosis plant operating at a flow of 2650 m^3/d (0.7 mgd). The example also includes an unlined brine evaporation lagoon, a ground-level steel clearwell, gas chlorination at a feed rate of 1.5 mg/L, and product water pumping. Included in the reverse osmosis unit process are sulfuric acid and sodium hexametaphosphate feed facilities, and feed dosages of 25 mg/L and 5 mg/L respectively, were used. The PROCES.DAT file for this example is presented in Table 199, and Table 200 is the summary output.

Example 3 - Package Pressure Filtration

This example is for a 2839 m^3/d (0.75 mgd) package pressure filtration plant, which is being operated at a flow rate of 1987 m^3/d (0.53 mgd). Included in the example are raw and product water pumping, polymer and gas chlorine feed, a ground-level steel clearwell, and sludge dewatering lagoons. The polymer and chlorine feed rates are 0.2 mg/L and 1.5 mg/L respectively. Table 201 presents the PROCES.DAT file for this example, and Table 202 presents the summary program output.

TROUBLESHOOTING GUIDE

The WATER program is designed to check the PROCES.DAT file before computing process costs to assure that all necessary data lines are present. If an error exists in this file, the program will print the type of error and the

```
                          COST SUMMARY FOR  6 WATER TREATMENT PROCESSES

              PROCESS                   FLOW-MGD           PROCESS PARAMETER           COSTS-DOLLARS        COSTS-CTS/1000 GAL
                                     DESIGN ACTUAL      DESIGN         OPERATING      CONSTR    CAPITAL    O&M    DEBT   TOTAL

 1. PACKAGE RAW WATER PUMPING STA.    0.500   0.350  720000.0 GPD   350000.0 GPD      44326      61375   2.315   5.643   7.958
 2. CONVEN. PCKG COMPL,5 GPM/SF,2 BW  0.500   0.350      87.0 SQ FT     60.0 SQ FT   350511     485333  16.860  44.624  61.484
      $ 150.00/TON FOR ALUM
      $4000.00/TON FOR POLYMER
 3. GAS FEED CHLOR., TO 40 LB/DAY     0.500   0.350      12.5 LB/DAY     4.3 LB/DAY   20230      28012   2.194   2.576   4.770
      $ 300.00/TON FOR CHLORINE - GAS
 4. GROUND-LEVEL STEEL CLEARWELLS     0.500   0.350  125000.0 GAL   125000.0 GAL      95267     131911   0.000  12.129  12.129
 5. PACKAGE HIGH SERVICE PUMPING STA  0.500   0.350  720000.0 GPD   350000.0 GPD      31827      44069   6.955   4.052  11.007
 6. SLUDGE DISPOSAL TO SANIT. SEWERS  0.500   0.350   16800.0 MG/L   16800.0 MG/L         0          0  14.911   0.000  14.911
      SLUDGE FLOW = 5000     GPD
                                                                            -----------------------------------------------

                                                                   TOTAL     542161     750701  43.236  69.023 112.259

                                               SITEWORK,SUBSURFACE,STNBY POWER   27108
                                                     GEN CON OH & P, 12.0%       68312
                                                               ENGINEERING       63758
                                                         LAND,    0.60 ACRES      1200
                                                       LEGAL,FISCAL,ADMIN        12571
                                                        INT DURING CONSTR        35590
                                                                            ---------
                                                           TOTAL CAPITAL        750701

TOTAL O&M:         KWH      MATERIALS,$        LABOR,HR        DIESEL,GAL       NAT GAS,CU FT      CHEMICALS,$     TOTAL,$/YR
                 164197          5135            1575               0                 0               2233           55234

PROCESS O&M
     1            28234           184              72               0                 0                  0            2958
     2            27773          4473            1193               0                 0               1997           21539
     3             2886           353             183               0                 0                235            2803
     4                0             0               0               0                 0                  0               0
     5           105304           125             126               0                 0                  0            8885
     6                0             0               0               0                 0                  0           19049

COSTS PRESENTED HAVE BEEN ADJUSTED TO DECEMBER 1983

        CAPITAL COST FACTORS                       UNIT COST FACTORS                            COST INDICES

   ENGINEERING(%)                 =10       ELECTRICITY, $/KWH               =.07       EXCAVATION(ENR SKILLED LABOR) =368.68
   SITEWORK, INTERFACE PIPING(%)  =5        LABOR, $/HR                      =11        MANUFACTURED EQUIP (BLS #114) =309.3
   SUBSURFACE CONSIDERATIONS(%)   =0        DIESEL FUEL, $/GAL               =1.10      CONCRETE (BLS #132)           =317.0
   STANDBY POWER(%)               =0        NATURAL GAS, $/CU FT             =.0055     STEEL (BLS #1017)             =359.5
   INTEREST RATE(%)               =10       BLDNG ENERGY USE,KWH/SQ FT/YR    =19.5      LABOR (ENR SKILLED LABOR)     =368.68
   NUMBER OF YEARS                =20                                                   PIPE & VALVES (BLS #1149)     =327.0
   LAND COST, $/ACRE              =2000                                                 ELECTRICAL & INSTR (BLS #117) =243.7
                                                                                        HOUSING (ENR BUILDING COST)   =356.30
                                                                                        PRODUCER PRICE INDEX          =287.1
                                                                                        ENR CONSTRUCTION, '67 BASE YR =0
```

TABLE 198. SUMMARY PROGRAM OUTPUT FOR EXAMPLE 1, CONVENTIONAL PACKAGE COMPLETE TREATMENT PLANT

TABLE 199. PROCES.DAT FILE FOR EXAMPLE 2, REVERSE OSMOSIS TREATMENT

```
ACRES=16.5
1,19,REVERSE OSMOSIS, TDS 5000 MG/L
2,1.,.7,1000000.,700000.
3,80.,145.95,SULFURIC ACID
4,1000.,29.2,HEXAMETAPHOSPHATE
5,0.,0.
1,97,BRINE EVAP LAGOONS, NO LINER
2,1.,.7,650000.,650000.
1,59,GROUND-LEVEL STEEL CLEARWELLS
2,1.,.7,125000.,125000.
1,23,GAS FEED CHLOR., TO 40 LB/DAY
2,1.,.7,25.,8.8
3,300.,CHLORINE GAS
1,30,PACKAGE HIGH SERVICE PUMPING STA
2,1.,.7,1250000.,700000.
```

TABLE 201. PROCES.DAT FILE FOR EXAMPLE 3, PACKAGE PRESSURE FILTRATION

```
ACRES=1.0
1,31,PACKAGE RAW WATER PUMPING STA
2,.75,.53,1000000.,530000.
1,71,BASIC POLYMER FEED, ONE TANK
2,.75,.53,6.3,0.88
3,4000.,POLYMER
1,9,PCKG PRESSURE FILT,2 GPM/SF,1 BW
2,.75,.53,104.,74.
3,0.0,0.0,SODIUM HYPOCHLORITE (NONE)
4,0.0,0.0,POLYMER (NONE)
5,0.0,0.0,POTASSIUM PERMANGANATE (NONE)
1,23,GAS FEED CHLOR., TO 40 LB/DAY
2,.75,.53,18.8,6.6
3,300.,CHLORINE GAS
1,59,GROUND-LEVEL STEEL CLEARWELLS
2,.75,.53,150000.,150000.
1,30,PACKAGE HIGH SERVICE PUMPING STA
2.,.75,.53,1000000.,530000.
1,86,SLUDGE DEWATERING LAGOONS
2,.75,.53,15000.,0.0
```

```
                         COST SUMMARY FOR  5 WATER TREATMENT PROCESSES

           PROCESS                     FLOW-MGD             PROCESS PARAMETER              COSTS-DOLLARS         COSTS-CTS/1000 GAL
                                    DESIGN ACTUAL       DESIGN          OPERATING        CONSTR     CAPITAL    O&M     DEBT    TOTAL

 1. REVERSE OSMOSIS, TDS 5000 MG/L    1.000   0.700  1000000.0 GPD    700000.0 GPD      1167018     1664619 101.652  76.527 178.179
     $  80.00/TON FOR SULFURIC ACID
     $1000.00/TON FOR HEXAMETAPHOSPHATE
 2. BRINE EVAP LAGOONS, NO LINER      1.000   0.700   650000.0 SQ FT  650000.0 SQ FT     376748      537389   1.067  24.705  25.772
 3. GROUND-LEVEL STEEL CLEARWELLS     1.000   0.700   125000.0 GAL    125000.0 GAL        95267      135888   0.000   6.247   6.247
 4. GAS FEED CHLOR., TO 40 LB/DAY     1.000   0.700       25.0 LB/DAY      8.8 LB/DAY     20230       28856   1.197   1.327   2.523
     $ 300.00/TON FOR CHLORINE - GAS
 5. PACKAGE HIGH SERVICE PUMPING STA  1.000   0.700  1250000.0 GPD    700000.0 GPD        40821       58227   6.380   2.677   9.057
                                                                                     ---------------------------------------------

                                                                        TOTAL       1700085     2424979 110.296 111.482 221.778

                                                 SITEWORK,SUBSURFACE,STNBY POWER      85004
                                                          GEN CON OH & P, 12.0%      214211
                                                                    ENGINEERING      199930
                                                             LAND,  16.50 ACRES       33000
                                                            LEGAL,FISCAL,ADMIN        25826
                                                              INT DURING CONSTR      166923
                                                                                    -------
                                                                  TOTAL CAPITAL     2424979

 TOTAL O&M:          KWH       MATERIALS,$          LABOR,HR          DIESEL,GAL        NAT GAS,CU FT        CHEMICALS,$      TOTAL,$/YR
                   2424215        89868               1300                0                  0                  7940            281805

 PROCESS O&M
     1             2213003        88151                837                0                  0                  7458            259721
     2                   0         1197                139                0                  0                     0              2726
     3                   0            0                  0                0                  0                     0                 0
     4                2952          356                183                0                  0                   482              3058
     5              208260          164                142                0                  0                     0             16301

 COSTS PRESENTED HAVE BEEN ADJUSTED TO DECEMBER 1983

          CAPITAL COST FACTORS                     UNIT COST FACTORS                            COST INDICES

   ENGINEERING(%)                  =10      ELECTRICITY, $/KWH              =.07       EXCAVATION(ENR SKILLED LABOR) =368.68
   SITEWORK, INTERFACE PIPING(%)   =5       LABOR, $/HR                     =11        MANUFACTURED EQUIP (BLS #114) =309.3
   SUBSURFACE CONSIDERATIONS(%)    =0       DIESEL FUEL, $/GAL              =1.10      CONCRETE (BLS #132)           =317.0
   STANDBY POWER(%)                =0       NATURAL GAS, $/CU FT            =.0055     STEEL (BLS #1017)             =359.5
   INTEREST RATE(%)                =10      BLDNG ENERGY USE,KWH/SQ FT/YR =19.5        LABOR (ENR SKILLED LABOR)     =368.68
   NUMBER OF YEARS                 =20                                                 PIPE & VALVES (BLS #1149)     =327.0
   LAND COST, $/ACRE               =2000                                               ELECTRICAL & INSTR (BLS #117) =243.7
                                                                                       HOUSING (ENR BUILDING COST)   =356.30
                                                                                       PRODUCER PRICE INDEX          =287.1
                                                                                       ENR CONSTRUCTION, '67 BASE YR =0
```

TABLE 200. SUMMARY PROGRAM OUTPUT FOR EXAMPLE 2
REVERSE OSMOSIS TREATMENT

```
                          COST SUMMARY FOR  7 WATER TREATMENT PROCESSES

           PROCESS                  FLOW-MGD           PROCESS PARAMETER              COSTS-DOLLARS        COSTS-CTS/1000 GAL
                                 DESIGN ACTUAL       DESIGN        OPERATING         CONSTR    CAPITAL     O&M     DEBT    TOTAL

 1. PACKAGE RAW WATER PUMPING STA.   0.750   0.530  1000000.0 GPD    530000.0 GPD      52396     72505   2.133    4.402    6.535
 2. BASIC POLYMER FEED, ONE TANK     0.750   0.530        6.3 LB/DAY      0.9 LB/DAY    5141      7114   1.808    0.432    2.240
      $4000.00/TON FOR POLYMER
 3. PCKG PRESSURE FILT,2 GPM/SF,1 BW 0.750   0.530      104.0 SQ FT      74.0 SQ FT   235306    325614   3.139   19.771   22.910
 4. GAS FEED CHLOR., TO 40 LB/DAY    0.750   0.530       18.8 LB/DAY      6.6 LB/DAY   20230     27995   1.516    1.700    3.216
      $ 300.00/TON FOR CHLORINE - GAS
 5. GROUND-LEVEL STEEL CLEARWELLS    0.750   0.530   150000.0 GAL    150000.0 GAL     106769    147745   0.000    8.971    8.971
 6. PACKAGE HIGH SERVICE PUMPING STA 0.750   0.530  1000000.0 GPD    530000.0 GPD      36954     51137   6.594    3.105    9.699
 7. SLUDGE DEWATERING LAGOONS        0.750   0.530    15000.0 CU FT       0.0 CF/YR     5481      7585   0.000    0.461    0.461
                                                                                 ----------------------------------------------
                                                                       TOTAL      462277    639694  15.191   38.841   54.032

                                                SITEWORK,SUBSURFACE,STNBY POWER    23114
                                                         GEN CON OH & P, 12.0%     58247
                                                                   ENGINEERING     54364
                                                            LAND,    1.00 ACRES     2000
                                                           LEGAL,FISCAL,ADMIN     11737
                                                             INT DURING CONSTR     27955
                                                                                 -------
                                                                 TOTAL CAPITAL    639694

TOTAL O&M:        KWH      MATERIALS,$      LABOR,HR     DIESEL,GAL      NAT GAS,CU FT      CHEMICALS,$    TOTAL,$/YR
                220943          1875          1003             0                0              1018          29386

PROCESS O&M
       1         42753           208            84             0                0                 0           4126
       2           233            42           253             0                0               657           3498
       3         16220          1126           347             0                0                 0           6072
       4          2916           355           183             0                0               361           2933
       5             0             0             0             0                0                 0              0
       6        158821           145           136             0                0                 0          12757
       7             0             0             0             0                0                 0              0

COSTS FOR THE FOLLOWING PROCESSES HAVE BEEN EXTRAPOLATED.  VALID RANGES ARE:

           PROCESS                     DESIGN RANGE           YOUR INPUT      OPERATING RANGE           YOUR INPUT
 3 PCKG PRESSURE FILT,2 GPM/SF,1 BW     0.3 TO      79.0 SQ FT     104.0      0.3 TO      79.0 SQ FT       74.0
 7 SLUDGE DEWATERING LAGOONS         2500.0 TO  147000.0 CU FT   15000.0    340.0 TO   19992.0 CF/YR       0.0
```

TABLE 202. SUMMARY PROGRAM OUTPUT FOR EXAMPLE 3
PACKAGE PRESSURE FILTRATION

```
COSTS PRESENTED HAVE BEEN ADJUSTED TO DECEMBER 1983

       CAPITAL COST FACTORS

   ENGINEERING(%)                      =10
   SITEWORK, INTERFACE PIPING(%)       =5
   SUBSURFACE CONSIDERATIONS(%)        =0
   STANDBY POWER(%)                    =0
   INTEREST RATE(%)                    =10
   NUMBER OF YEARS                     =20
   LAND COST, $/ACRE                   =2000

          UNIT COST FACTORS

   ELECTRICITY, $/KWH                  =.07
   LABOR, $/HR                         =11
   DIESEL FUEL, $/GAL                  =1.10
   NATURAL GAS, $/CU FT                =.0055
   BLDNG ENERGY USE,KWH/SQ FT/YR       =19.5

             COST INDICES

   EXCAVATION(ENR SKILLED LABOR) =368.68
   MANUFACTURED EQUIP (BLS #114) =309.3
   CONCRETE (BLS #132)           =317.0
   STEEL (BLS #1017)             =359.5
   LABOR (ENR SKILLED LABOR)     =368.68
   PIPE & VALVES (BLS #1149)     =327.0
   ELECTRICAL & INSTR (BLS #117) =243.7
   HOUSING (ENR BUILDING COST)   =356.30
   PRODUCER PRICE INDEX          =287.1
   ENR CONSTRUCTION, '67 BASE YR =0
```

TABLE 202. (Continued)

line number in which the error occurred. The program also checks the length of the COST.DAT file to assure that it contains either 28 or 30 lines. The following self-explanatory error messages are contained in the program:

1. FORTRAN read error in line _____ of the PROCES.DAT file. This line should contain the word "ACRES=" followed by a floating point number of 15 digits or less.

2. Error - line with "ACRES=" is missing or misspelled. Check line _____ of the PROCES.DAT file.

3. FORTRAN read error in line _____ of the PROCES.DAT file. This line should contain the integer 1 followed by a comma, the process number, and name.

4. Error - this should be the first data line of a process and should begin with the integer 1 in column 1. Check line _____ of the PROCES.DAT file.

5. Error in line ____ of the PROCES.DAT file. ____ is an invalid process number. Processes are numbered 1 through 100 in Table 194 of the program manual.

6. Error in line _____ of the PROCES.DAT file. Line number _____ was expected for process ____, which requires ____ lines of data.

7. Error - not enough data in the COST.DAT file; this file should have either 28 or 30 lines.

In addition to the error messages, the program also notifies the user when his input data exceeds the valid range of the stored cost data. In this case, the computer extrapolates the stored data. See Table 202 for a sample listing of this situation.

Errors may arise that will not cause an error message or program interruption if the required commas between the input data values are forgotten. In this case, erroneous input values will result. If this happens, check the PROCES.DAT file for required commas.

WATER PROGRAM LISTING

The WATER program is written specifically for the DEC PDP-1170 IAS computing system. Because this FORTRAN program may not be compatible with all systems, it may be necessary to modify the opening and closing of data files. Also, FORMAT statements do not contain the Holerith or H-conversion; instead they transmit alphanumeric data by enclosing it directly in quotation marks. The WATER program is presented in Table 203.

CRV.DAT FILE

The CRV.DAT file contains all the cost information for the water treatment processes included in this report. The WATER program reads this file in a

TABLE 203. PROGRAM LISTING

```
      INTEGER O,REPEAT,REDO
      REAL M,L,MAINT,LABOR,LFAFEE
      LOGICAL DLIMIT,OLIMIT
      DIMENSION TDH(10),TMILE1(10),GPMSF1(10),AMAKUP(10),
     : AMGL(10),VAR(22),VARVAL(10),IRANGE(150),NP(150),APCENT(10)
      DIMENSION NCHEM(75),CMNAM(75,3),CMCST(75),CMAMT(75),ITYPE(150)
      DIMENSION SAVE1(10)
      DOUBLE PRECISION OUTPUT,PROCES,DETAILED,DXU,OXU,CMNAM,CHECK1,CHECK
      DIMENSION CONSTR(150),ELECTR(150),MAINT(150),LABOR(150),
     : DIESEL(150),GAS(150),CHEM(150),QD(150),QA(150),DPV(150),
     : OPV(150),PROCAP(150),CTSTOM(150),CTSDEB(150),CTSTL(150),
     : NUMUN(150),DXU(150),OXU(150)
      DIMENSION C(4),E(4),M(4),L(4),D(4),G(4),F(8),B(4)
      DIMENSION PROCES(150,4),CTS(150)
      COMMON NUMUN,N/A/TOP,BOTTOM,C,B,CI/B/OTOP,OBOT,E,M,L,D,G,CR9
      COMMON/C/ENGR,SITE,SUBSUR,STNBY,RATE,YEARS,CLAND,ELEC,
     : HOURLY,FUEL,GASCST,ENFT,CI1,CI2,CI3,CI4,CI5,CI6,CI7,CI8,CI9,
     : CI10
      EQUIVALENCE (ENGR,VAR(1))
      DATA IVV,DETAILED,CHECK1/0,'DETAILED','ACRES='/
      OPEN(UNIT=1,NAME='COST.DAT',TYPE='OLD')
      READ(1,100,END=240) ENGR,SITE,SUBSUR,STNBY,RATE,YEARS,CLAND
      READ(1,101,END=240) ELEC,HOURLY,FUEL,GASCST,ENFT
      READ(1,102,END=240) CI1,CI2,CI3,CI4,CI5,CI6,CI7,CI8,CI9,CI10
      READ(1,103,END=240) O,OUTPUT
      READ(1,105,END=450) IVN,IVV
      IF(IVN.LE.0.OR.IVN.GT.22) GOTO 620
      READ(1,106,END=240) (VARVAL(I1),I1=1,IVV)
  450 IVV=IVV+1
      CLOSE(UNIT=1)
      DO 610 REDO=1,IVV
      IF(REDO.GT.1) VAR(IVN)=VARVAL(REDO-1)
      CR1=CI1/247.0
      CR2=CI2/221.3
      CR3=CI3/221.1
      CR4=CI4/262.1
      CR5=CI5/247.0
      CR6=CI6/236.4
      CR7=CI7/167.5
      CR8=CI8/254.76
      CR9=CI9/199.7
      CR10=CI10/265.38
      OPEN(UNIT=2,NAME='PROCES.DAT',TYPE='OLD')
      NCASE=0
      ILINE=0
  198 ILINE=ILINE+1
      READ(2,151,END=251,ERR=210) CHECK,ACRES
      IF(CHECK.NE.CHECK1) GOTO 215
  199 ILINE=ILINE+1
      READ(2,152,END=250,ERR=220) NCHCK,NP(1)
      IF(NCHCK.EQ.0.AND.ILINE.GT.3) GOTO 245
      IF(NCHCK.NE.1) GOTO 225
      IF(NP(1).LE.0.OR.NP(1).GT.131) GOTO 230
      IZ=1+(NP(1)-1)*5
      OPEN(UNIT=3,NAME='CRV.DAT',TYPE='OLD',ACCESS='DIRECT',
     : FORM='FORMATTED',ASSOCIATEVARIABLE=IZN)
      READ(3'IZ,153) (PROCES(1,I1),I1=1,4),NCHEM(1),ITYPE(1)
      CLOSE(UNIT=3)
      GOTO(200,200,201,201,201,201,201,201,201,200,201,202)ITYPE(1)
  200 NCARD=2+NCHEM(1)
      GOTO 203
  201 NCARD=3+NCHEM(1)
      GOTO 203
  202 NCARD=4+NCHEM(1)
  203 DO 205 I1=2,NCARD
      ILINE=ILINE+1
      READ(2,154,END=235,ERR=235) NCHCK
      IF(NCHCK.NE.I1) GOTO 235
  205 CONTINUE
      GOTO 199
  210 WRITE(O,370) ILINE
      GOTO 1000
  215 WRITE(O,371) ILINE
      GOTO 1000
  220 WRITE(O,372) ILINE
      GOTO 1000
  225 WRITE(O,373) ILINE
      GOTO 1000
  230 WRITE(O,374) ILINE,NP(1)
      GOTO 1000
```

TABLE 203. (Continued)

```
 235 WRITE(0,375) ILINE,I1,NP(1),(PROCES(1,I2),I2=1,4),NCARD
     GOTO 1000
 240 WRITE(0,376)
     GOTO 1000
 245 NCASE=NCASE+1
     GOTO 198
 250 NCASE=NCASE+1
 251 CLOSE(UNIT=2)
     OPEN(UNIT=2,NAME='PROCES.DAT' ,TYPE='OLD')
     DO 600 REPEAT=1,NCASE
     ICHEM2=0
     ITDH=0
     IMILES=0
     IMAKUP=0
     IGPM=0
     IMGL=0
     IPCENT=0
     N=0
     IPAGE=0
     TCOST=0.0
     TCTSE=0.0
     TCTSM=0.0
     TCTSL=0.0
     TCTSD=0.0
     TCTSG=0.0
     TCTSC=0.0
     TE=0.0
     TM=0.0
     TL=0.0
     TD=0.0
     TG=0.0
     TC=0.0
     SUM1=0.0
     SUM2=0.0
     SUM3=0.0
     SUM4=0.0
     SUM5=0.0
     READ(2,127) ACRES
 500 READ(2,110,END=531) NP(N+1)
     IF(NP(N+1).LE.0) GOTO 531
     N=N+1
     READ(2,115) QD(N),QA(N),DPV(N),OPV(N)
     IZ= 1 + (NP(N)-1)*5
     OPEN(UNIT=3,NAME='CRV.DAT',TYPE='OLD',ACCESS='DIRECT',
    : FORM='FORMATTED',ASSOCIATEVARIABLE=IZN)
     READ(3'IZ,120)(PROCES(N,I1),I1=1,4),DXU(N),OXU(N),BOTTOM,TOP,
    : PROP,IRATIO,IEXP,NCHEM(N),ITYPE(N)
     READ(3'IZ+1 ,121) C,E
     READ(3'IZ+2  ,121) M,L
     READ(3'IZ+3  ,121) D,G
     READ(3'IZ+4  ,122) B,F
     CLOSE(UNIT=3)
     IF(ITYPE(N).EQ.4.OR.ITYPE(N).EQ.6) GOTO 501
     OBOT=BOTTOM*PROP
     OTOP=TOP*PROP
     GOTO 502
 501 OBOT=PROP
     OTOP=IRATIO*(10.0**IEXP)
 502 DLIMIT=DPV(N).LT.BOTTOM.OR.DPV(N).GT.TOP
     OLIMIT=OPV(N).LT.OBOT.OR.OPV(N).GT.OTOP
     RATIO=IRATIO*(10.0**IEXP)
     CI=F(1)*CR1 + F(2)*CR2 + F(3)*CR3 + F(4)*CR4 + F(5)*CR5 +
    :    F(6)*CR6 + F(7)*CR7 + F(8)*CR8
     IF(CI.LT.0.01) CI=CR9
     IF(CR10.GT.0.0) CI=CR10
     CHEM(N)=0.0
     NUMUN(N)=1
     IRANGE(N)=0
     W1=DPV(N)**2
     W2=DPV(N)**3
     W3=OPV(N)**2
     W4=OPV(N)**3
     CTS(N)=QA(N)*3650.
     GOTO(505,505,504,525,505,505,505,505,550,505,505,504)ITYPE(N)
 504 READ(2,110) NUMUN(N)
```

TABLE 203. (Continued)

```
 505 CONSTR(N)=(C(1)+C(2)*DPV(N)+C(3)*W1+C(4)*W2)*NUMUN(N)*CI
     BLDEN    =(B(1)+B(2)*DPV(N)+B(3)*W1+B(4)*W2)*ELEC*ENFT/102.6
     ELECTR(N)=(E(1)+E(2)*OPV(N)+E(3)*W3+E(4)*W4)*NUMUN(N)*ELEC
     MAINT(N) =(M(1)+M(2)*OPV(N)+M(3)*W3+M(4)*W4)*NUMUN(N)*CR9
     LABOR(N) =(L(1)+L(2)*OPV(N)+L(3)*W3+L(4)*W4)*NUMUN(N)*HOURLY
     DIESEL(N)=(D(1)+D(2)*OPV(N)+D(3)*W3+D(4)*W4)*NUMUN(N)*FUEL
     GAS(N)   =(G(1)+G(2)*OPV(N)+G(3)*W3+G(4)*W4)*NUMUN(N)*GASCST
     IF(DLIMIT) CALL DRANGE(CONSTR(N),BLDEN,DPV(N))
     IF(OLIMIT) CALL ORANGE(ELECTR(N),MAINT(N),LABOR(N),DIESEL(N),
    : GAS(N),OPV(N))
     IF(DLIMIT.OR.OLIMIT) IRANGE(N)=1
     ELECTR(N)=ELECTR(N)+BLDEN
     GOTO(510,520,510,510,530,535,540,545,510,510,554,557)ITYPE(N)
                **TYPE 1**
 510 IF(NCHEM(N).EQ.0) GOTO 526
     ICHEM1=ICHEM2+1
     ICHEM2=ICHEM2+NCHEM(N)
     DO 515 I1=ICHEM1,ICHEM2
     READ(2,111) CMCST(I1),(CMNAM(I1,I2),I2=1,3)
     CMAMT(I1)=OPV(N)*RATIO*365./2000.
     CHEM(N)=CHEM(N)+CMCST(I1)*CMAMT(I1)
               **TYPE 10**
     IF(ITYPE(N).EQ.10) CHEM(N)=CHEM(N)*2000.0
 515 CONTINUE
     GOTO 526
              **TYPE 2**
 520 ICHEM1=ICHEM2+1
     ICHEM2=ICHEM2+NCHEM(N)
     DO 522 I1=ICHEM1,ICHEM2
     READ(2,113) CMCST(I1),CMAMT(I1),(CMNAM(I1,I2),I2=1,3)
     CMAMT(I1)=CMAMT(I1)*365./2000.
 522 CHEM(N)=CHEM(N)+CMCST(I1)*CMAMT(I1)
     GOTO 526
             **TYPE 4**
 525 READ(2,110) NUMUN(N)
     CONSTR(N)=(C(1)+C(2)*DPV(N)+C(3)*W1+C(4)*W2)*NUMUN(N)*CI
     BLDEN=(B(1)+B(2)*OPV(N)+B(3)*W3+B(4)*W4)*ELEC*ENFT/102.6
     IF(DLIMIT) CALL DRANGE(CONSTR(N),W1,DPV(N))
     ELECTR(N)=(E(1)+E(2)*OPV(N)+E(3)*W3+E(4)*W4)*ELEC
     MAINT(N)=(M(1)+M(2)*OPV(N)+M(3)*W3+M(4)*W4)*CR9
     LABOR(N)=(L(1)+L(2)*OPV(N)+L(3)*W3+L(4)*W4)*HOURLY
     IF(OLIMIT) GOTO 527
     GOTO 528
 527 ISAVE=NUMUN(N)
     NUMUN(N)=1
     CALL ORANGE(ELECTR(N),MAINT(N),LABOR(N),DIESEL(N),
    : GAS(N),OPV(N))
     NUMUN(N)=ISAVE
     TOP=OTOP
     BOTTOM=OBOT
     CALL DRANGE(W1,BLDEN,OPV(N))
 528 IF(DLIMIT.OR.OLIMIT) IRANGE(N)=1
     ELECTR(N)=ELECTR(N)+BLDEN
     DIESEL(N)=0.0
     GAS(N)=0.0
     CHEM(N)=0.0
     GOTO 526
             **TYPE 5**
 530 ITDH=ITDH+1
     READ(2,123) TDH(ITDH)
     BLDEN=BLDEN*102.6/ELEC/ENFT*CI
     ELECTR(N)=ELECTR(N)*TDH(ITDH)/D(1)
     DIESEL(N)=0.0
     DENOM=D(1)-D(2)
     SLOPE=(CONSTR(N)-BLDEN)/DENOM
     BEE=(D(1)*BLDEN-D(2)*CONSTR(N))/DENOM
     CONSTR(N)=SLOPE*TDH(ITDH) + BEE
     BLDEN=0.0
     GOTO 526
             **TYPE 6**
 535 IMILES=IMILES+1
     READ(2,123) TMILE1(IMILES)
     TMILES=TMILE1(IMILES)
     MAINT(N)=MAINT(N)*TMILES
     IF(TMILES.LE.25.0) LABOR(N)=LABOR(N)*(0.4133*TMILES+5.867)
     IF(TMILES.GT.25.0) LABOR(N)=LABOR(N)*(14.71+TMILES/17.0)
     DIESEL(N)=DIESEL(N)*TMILES
     CHEM(N)=0.0
     GOTO 526
```

TABLE 203. (Continued)

```
C                **TYPE 7**
  540 IMILES=IMILES+1
      READ(2,123) TMILE1(IMILES)
      TMILES=TMILE1(IMILES)
      ELECTR(N)=ELECTR(N)/ELEC*CI
      SLOPE=(ELECTR(N)-CONSTR(N))/35.0
      BEE=(40.0*CONSTR(N)-5.0*ELECTR(N))/35.0
      CONSTR(N)=SLOPE*TMILES + BEE
      IF(TMILES.LE.20) LABOR(N)=LABOR(N)*(0.667+0.0667*TMILES)
      IF(TMILES.GT.20) LABOR(N)=LABOR(N)*(1.0+0.05*TMILES)
      MAINT(N)=MAINT(N)*TMILES/5.0
      GAS(N)=0.0
      DIESEL(N)=DIESEL(N)*TMILES/5.0
      ELECTR(N)=0.0
      BLDEN=0.0
      CHEM(N)=0.0
      GOTO 526
C                **TYPE 8**
  545 IMAKUP=IMAKUP+1
      READ(2,123) AMAKUP(IMAKUP)
      ICHEM2=ICHEM2+1
      READ(2,111) CMCST(ICHEM2),(CMNAM(ICHEM2,I1),I1=1,3)
      CMAMT(ICHEM2)=OPV(N)*RATIO*365./2000.*AMAKUP(IMAKUP)/100.
      CHEM(N)=CMCST(ICHEM2)*CMAMT(ICHEM2)
      GOTO 526
C                **TYPE 9**
  550 IGPM=IGPM+1
      READ(2,123) GPMSF1(IGPM)
      GPMSF=GPMSF1(IGPM)
      IF(GPMSF.EQ.0.0) GPMSF=2.0
      W1=DPV(N)/GPMSF
      W2=W1**2
      W3=W1**3
      BOTTOM=BOTTOM/2.0
      TOP=TOP/5.0
      DLIMIT=W1.LT.BOTTOM.OR.W1.GT.TOP
      CONSTR(N)=(C(1)+C(2)*W1+C(3)*W2+C(4)*W3)*CI
      BLDEN=(B(1)+B(2)*W1+B(3)*W2+B(4)*W3)*ELEC*ENFT/102.6
      IF(DLIMIT) CALL DRANGE(CONSTR(N),BLDEN,W1)
      W1=OPV(N)/GPMSF
      W2=W1**2
      W3=W1**3
      ELECTR(N)=(E(1)+E(2)*W1+E(3)*W2+E(4)*W3)*ELEC
      MAINT(N)=(M(1)+M(2)*W1+M(3)*W2+M(4)*W3)*CR9
      LABOR(N)=(L(1)+L(2)*W1+L(3)*W2+L(4)*W3)*HOURLY
      OLIMIT=W1.LT.BOTTOM.OR.W1.GT.TOP
      IF(OLIMIT) CALL ORANGE(ELECTR(N),MAINT(N),LABOR(N),DIESEL(N),
     : GAS(N),W1)
      IF(DLIMIT.OR.OLIMIT) IRANGE(N)=1
      ELECTR(N)=ELECTR(N)*GPMSF/2.0+BLDEN
      DIESEL(N)=0.0
      GAS(N)=0.0
      ICHEM1=ICHEM2+1
      ICHEM2=ICHEM2+NCHEM(N)
      DO 548 I1=ICHEM1,ICHEM2
      READ(2,113) CMCST(I1),CMAMT(I1),(CMNAM(I1,I2),I2=1,3)
      CMAMT(I1)=CMAMT(I1)*365./2000.
  548 CHEM(N)=CHEM(N)+CMCST(I1)*CMAMT(I1)
      GOTO 526
C                **TYPE 11**
  554 IMGL=IMGL+1
      READ(2,123) AMGL(IMGL)
      SAVE1(IMGL)=CONSTR(N)*AMGL(IMGL)/D(1)
      CONSTR(N)=0.0
      DIESEL(N)=0.0
      GOTO 526
C                **TYPE 12**
  557 IPCENT=IPCENT+1
      READ(2,123) APCENT(IPCENT)
      CONSTR(N)=CONSTR(N)*APCENT(IPCENT)/100.
      ELECTR(N)=ELECTR(N)*APCENT(IPCENT)/100.
      MAINT(N) =MAINT(N) *APCENT(IPCENT)/100.
      LABOR(N) =LABOR(N) *APCENT(IPCENT)/100.
      DIESEL(N)=DIESEL(N)*APCENT(IPCENT)/100.
      GAS(N)   =GAS(N)   *APCENT(IPCENT)/100.
      CHEM(N)=0.0
      GOTO 526
  526 TCOST=TCOST+CONSTR(N)
      GOTO 500
```

TABLE 203. (Continued)

```
  531 CSTSIT=SITE*TCOST/100.
      CSTSUB=SUBSUR*TCOST/100.
      CSTSTN=STNBY*TCOST/100.
      SUBTL1=TCOST + CSTSIT + CSTSUB + CSTSTN
      OHP=12.
      IF(SUBTL1.GE.2.5E6.AND.SUBTL1.LT.10.E6) OHP=10.
      IF(SUBTL1.GE.10.E6.AND.SUBTL1.LT.25.E6) OHP=9.
      IF(SUBTL1.GE.25.E6) OHP=8.5
      CSTOHP=OHP*SUBTL1/100.
      SUBTL2=CSTOHP + SUBTL1
      CSTENG=ENGR*SUBTL2/100.
      SUBTL3=CSTENG + SUBTL2
      CSTLND=ACRES*CLAND
      IF(SUBTL3.GT.1.E6) GOTO 551
      IF(SUBTL3.LE.0.0) GOTO 552
      LFAFEE=60.0+.0447*SUBTL3-6.406E-8*SUBTL3**2+3.673E-14*SUBTL3**3
      BR=SUBTL3/1.E4
      CSTINT=(1.75+.252*BR-2.105E-3*BR**2+9.013E-6*BR**3)/
     : 24.*RATE*SUBTL3/100.
      GOTO 555
  551 LFAFEE=125570.+6.823E-4*SUBTL3-115564.*EXP(-6.015E-8*SUBTL3)
      BR=SUBTL3/1.E6
      CSTINT=(16.03+1.02*BR-1.188E-2*BR**2+3.7E-5*BR**3)/
     :       24.*RATE*SUBTL3/100.
      GOTO 555
  552 LFAFEE=0.0
      CSTINT=0.0
  555 TCAP=SUBTL3 + CSTLND + LFAFEE + CSTINT
      W1=(1.+RATE/100.)
      DEBT=TCAP*RATE/100.*W1**YEARS/(W1**YEARS-1.)
      IMGL=0
      DO 570 I=1,N
      IF(TCOST.LE.0.0) GOTO 556
      GOTO 558
  556 W2=0.0
      GOTO 559
  558 W2=CONSTR(I)/TCOST
  559 PRDEBT=DEBT*W2
      OTHER=(TCAP-TCOST)*W2
      PROCAP(I)=CONSTR(I) + OTHER
      CTSELE=ELECTR(I)/CTS(I)
      CTSMAI=MAINT(I)/CTS(I)
      CTSLAB=LABOR(I)/CTS(I)
      CTSDIE=DIESEL(I)/CTS(I)
      CTSGAS=GAS(I)/CTS(I)
      CTSCHE=CHEM(I)/CTS(I)
      CTSDEB(I)=PRDEBT/CTS(I)
      CTSTOM(I)=CTSELE+CTSMAI+CTSLAB+CTSDIE+CTSGAS+CTSCHE
      IF(ITYPE(I).EQ.11) IMGL=IMGL+1
      IF(ITYPE(I).EQ.11) CTSTOM(I)=SAVE1(IMGL)/CTS(I)
      CTSTL(I)=CTSDEB(I) + CTSTOM(I)
      TOM=ELECTR(I)+MAINT(I)+LABOR(I)+DIESEL(I)+GAS(I)+CHEM(I)
      IF(ITYPE(I).EQ.11) TOM=SAVE1(IMGL)
      TOTAL=TOM + PRDEBT
      TCTSE=TCTSE + CTSELE
      TCTSM=TCTSM + CTSMAI
      TCTSL=TCTSL + CTSLAB
      TCTSD=TCTSD + CTSDIE
      TCTSG=TCTSG + CTSGAS
      TCTSC=TCTSC + CTSCHE
      TE=TE + ELECTR(I)
      TM=TM + MAINT(I)
      TL=TL + LABOR(I)
      TD=TD + DIESEL(I)
      TG=TG + GAS(I)
      TC=TC + CHEM(I)
      SUM1=SUM1 + CTSDEB(I)
      SUM2=SUM2 + CTSTOM(I)
      SUM3=SUM3 + CTSTL(I)
      SUM4=SUM4 + TOM
      SUM5=SUM5 + TOTAL
      IF(OUTPUT.NE.DETAILED) GOTO 570
      IF(IPAGE.EQ.0) WRITE (0,300)
      IF(IPAGE.EQ.0) IPAGE=2
      IF(NUMUN(I).GT.1) GOTO 560
      WRITE(0,301) (PROCES(I,I1),I1=1,4),QD(I),QA(I),DPV(I),DXU(I),
     : OPV(I),OXU(I)
      WRITE(0,302) CONSTR(I),OTHER,PROCAP(I)
      GOTO 565
```

TABLE 203. (Continued)

```
  560 IF(NUMUN(N).EQ.0) GOTO 561
      QD(I)=QD(I)/NUMUN(I)
      QA(I)=QA(I)/NUMUN(I)
  561 WRITE(0,303) (PROCES(I,I1),I1=1,4),NUMUN(I),QD(I),QA(I),DPV(I),
     : DXU(I),OPV(I),OXU(I)
      QD(I)=QD(I)*NUMUN(I)
      QA(I)=QA(I)*NUMUN(I)
      WRITE(0,304) NUMUN(I),CONSTR(I),OTHER,PROCAP(I),NUMUN(I)
  565 WRITE(0,305) ELEC,CTSELE,ELECTR(I),CTSMAI,MAINT(I),HOURLY,
     : CTSLAB,LABOR(I),FUEL,CTSDIE,DIESEL(I)
      WRITE(0,306) GASCST,CTSGAS,GAS(I),CTSCHE,CHEM(I),CTSTOM(I),TOM
      WRITE(0,307) CTSTOM(I),TOM,YEARS,RATE,CTSDEB(I),PRDEBT,
     : CTSTL(I),TOTAL
      IPAGE=IPAGE-1
  570 CONTINUE
      IF(OUTPUT.NE.DETAILED) GOTO 571
      WRITE(0,300)
      WRITE(0,308) TCOST,SITE,CSTSIT
      IF(SUBSUR.GT.0.) WRITE(0,309) SUBSUR,CSTSUB
      IF(STNBY.GT.0.) WRITE(0,310) STNBY,CSTSTN
      WRITE(0,311) SUBTL1,OHP,CSTOHP,SUBTL2,ENGR,CSTENG,SUBTL3
      ICLAND=CLAND
      IF(ACRES.GT.0.) WRITE(0,312) ACRES,ICLAND,CSTLND
      WRITE(0,313) LFAFEE,CSTINT,TCAP
      WRITE(0,314) ELEC,TCTSE,TE,TCTSM,TM,HOURLY,TCTSL,TL,FUEL,TCTSD,TD
      WRITE(0,315) GASCST,TCTSG,TG,TCTSC,TC,SUM2,SUM4
      WRITE(0,316) SUM2,SUM4,YEARS,RATE,SUM1,DEBT,SUM3,SUM5
  571 ICHEM2=0
      ITDH=0
      IMILES=0
      IMAKUP=0
      IGPM=0
      IMGL=0
      IPCENT=0
      I3=0
      WRITE(0,300)
      I3=I3+8
      IF(N.GT.1) GOTO 575
      WRITE(0,317)
      GOTO 578
  575 WRITE(0,318) N
  578 WRITE(0,319)
      DO 590 I=1,N
      IF(I3-45) 583,580,581
  580 IF(N-I) 581,583,581
  581 IF(I3-63.LT.0.AND.N-I-1.GT.0) GOTO 583
  582 I3=0
      WRITE(0,300)
      WRITE(0,318) N
      WRITE(0,319)
      I3=I3+8
  583 WRITE(0,320) I,(PROCES(I,I1),I1=1,4),QD(I),QA(I),DPV(I),DXU(I),
     : OPV(I),OXU(I),CONSTR(I),PROCAP(I),CTSTOM(I),CTSDEB(I),CTSTL(I)
      I3=I3+1
      GOTO(735,735,700,705,710,715,715,720,725,735,730,732)ITYPE(I)
  700 WRITE(0,331) NUMUN(I)
      I3=I3+1
      GOTO 735
  705 W3=DPV(I)*NUMUN(I)*7.48/QD(I)/694.44
      WRITE(0,332) W3
      W3=DPV(I)*NUMUN(I)
      WRITE(0,341) W3,NUMUN(I)
      I3=I3+3
      GOTO 735
  710 ITDH=ITDH+1
      WRITE(0,333) TDH(ITDH)
      I3=I3+1
      GOTO 735
  715 IMILES=IMILES+1
      WRITE(0,334) TMILE1(IMILES)
      I3=I3+1
      GOTO 735
  720 IMAKUP=IMAKUP+1
      WRITE(0,335) AMAKUP(IMAKUP)
      I3=I3+1
      GOTO 735
  725 IGPM=IGPM+1
      WRITE(0,336) GPMSF1(IGPM)
      I3=I3+1
      GOTO 735
```

TABLE 203. (Continued)

```
  730 IMGL=IMGL+1
      WRITE(0,337) AMGL(IMGL)
      I3=I3+1
      GOTO 735
  732 IPCENT=IPCENT+1
      WRITE(0,331) NUMUN(I)
      WRITE(0,339) APCENT(IPCENT)
      I3=I3+2
      GOTO 735
  735 IF(NCHEM(I).EQ.0) GOTO 590
      ICHEM1=ICHEM2+1
      ICHEM2=ICHEM2+NCHEM(I)
      DO 585 I2=ICHEM1,ICHEM2
      IF(ITYPE(I).EQ.10) GOTO 584
      IF(CMAMT(I2).LE.0.0) GOTO 585
      WRITE(0,321) CMCST(I2),(CMNAM(I2,I4),I4=1,3)
      I3=I3+1
      GOTO 585
  584. WRITE(0,328) CMCST(I2),(CMNAM(I2,I4),I4=1,3)
      I3=I3+1
  585 CONTINUE
  590 CONTINUE
      WRITE(0,322) TCOST,TCAP,SUM2,SUM1,SUM3
      I3=I3+4
      SUM6=CSTSIT+CSTSUB+CSTSTN
      WRITE(0,329) SUM6,OHP,CSTOMP,CSTENG,ACRES,CSTLND,LFAFEE,
     : CSTINT,TCAP
      I3=I3+11
      TE=TE/ELEC
      TL=TL/HOURLY
      TD=TD/FUEL
      TG=TG/GASCST
      WRITE(0,330) TE,TM,TL,TD,TG,TC
      I3=I3+3
      IF(N-1.EQ.0) GOTO 7778
      IF(I3-60.GT.0) WRITE(0,300)
      WRITE(0,351)
      I3=I3+2
      DO 7777 I=1,N
      IF(I3-63.LT.0) GOTO 7776
      WRITE(0,300)
      WRITE(0,354)
      I3=3
 7776 TMP1=ELECTR(I)/ELEC
      TMP2=LABOR(I)/HOURLY
      TMP3=DIESEL(I)/FUEL
      TMP4=GAS(I)/GASCST
      WRITE(0,350) I,TMP1,MAINT(I),TMP2,TMP3,TMP4,CHEM(I)
 7777 I3=I3+1
 7778 I8=0
      DO 592 I=1,N
  592 I8=I8+IRANGE(I)
      IF(I8.EQ.0) GOTO 593
      IF(58-I3-I8.LT.0) WRITE(0,300)
      IF(58-I3-I8.LT.0) I3=0
      I8=0
  593 DO 596 I=1,N
      IF(IRANGE(I).EQ.0) GOTO 596
      IF(I8.GT.0) GOTO 594
      IF(I3-63.EQ.0) WRITE(0,300)
      IF(I3-63.EQ.0) I3=0
      WRITE(0,352)
      I8=I8+1
      I3=I3+4
  594 IZ=1+(NP(I)-1)*5
      OPEN(UNIT=3,NAME='CRV.DAT',TYPE='OLD',ACCESS='DIRECT',
     : FORM='FORMATTED',ASSOCIATEVARIABLE=IZN)
      READ(3'IZ,125) BOTTOM,TOP,PROP,IRATIO,IEXP
      CLOSE(UNIT=3)
      IF(ITYPE(I).EQ.4.OR.ITYPE(I).EQ.6) GOTO 597
      OBOT=BOTTOM*PROP
      OTOP=TOP*PROP
      GOTO 595
  597 OBOT=PROP
      OTOP=IRATIO*(10.0**IEXP)
  595 WRITE(0,353) I,(PROCES(I,I1),I1=1,4),BOTTOM,TOP,DXU(I),DPV(I),
     : OBOT,OTOP,OXU(I),OPV(I)
      I3=I3+1
```

TABLE 203. (Continued)

```
 596 CONTINUE
     OPEN(UNIT=1,NAME='COST.DAT',TYPE='OLD')
     IF(I3.GT.47) WRITE(0,300)
     READ(1,104) B,F
     WRITE(0,323) B,F
     WRITE(0,324) ENGR,ELEC,CI1,SITE,HOURLY,CI2
     WRITE(0,325) SUBSUR,FUEL,CI3,STNBY,GASCST,CI4,RATE,ENFT,CI5
     WRITE(0,326) YEARS,CI6,ACRES,CI7,CLAND,CI8,CI9
     IF(CI10.GT.0.01) WRITE (0,327) CI10
     CLOSE(UNIT=1)
 600 CONTINUE
     CLOSE(UNIT=2)
 610 CONTINUE
     GOTO 1000
 620 WRITE(0,338) IVN
1000 STOP
 100 FORMAT(//6(34X,F9.2/),34X,F9.2)
 101 FORMAT(/4(34X,F9.2/),34X,F9.2)
 102 FORMAT(/9(34X,F9.2/),34X,F9.2)
 103 FORMAT(34X,I1/34X,A8)
 104 FORMAT(4A4,8A4)
 105 FORMAT(I,I1)
 106 FORMAT(10F)
 110 FORMAT(2X,I)
 111 FORMAT(2X,F,3A8)
 113 FORMAT(2X,2F,3A8)
 114 FORMAT(2X,I,F)
 115 FORMAT(2X,4F)
 120 FORMAT(4A8,2A6,3E9.2,I4,I2,I1,I2)
 121 FORMAT(4E10.2,4E10.2)
 122 FORMAT(4E10.2,8F5.3)
 123 FORMAT(2X,F)
 125 FORMAT(44X,3E9.2,I4,I2)
 127 FORMAT(6X,F)
 151 FORMAT(A6,F)
 152 FORMAT(2I)
 153 FORMAT(4A8,45X,I1,I2)
 154 FORMAT(I)
 300 FORMAT(1H1)
 301 FORMAT(//' ***** COST ESTIMATE FOR '4A8//T48,'DESIGN'T66,
    : 'OPERATING'/T12,'PROCESS FLOW'T41,F10.3,' MGD'T61,F10.3,
    : ' MGD'/T12,'PROCESS PARAMETER'T41,F10.2,1X,A6,T61,F10.2,1X,A6/)
 302 FORMAT(T8,'CAPITAL COST'T55,'DOLLARS'//
    : T12,'CONSTRUCTION'T52,F11.0/T12,'OTHER RELATED COSTS'T52,F11.0/
    : T53,'------------'/T30,'PROCESS CAPITAL COST'T52,F11.0//
    : T8,'O&M COST'T49,'CTS/1000 GAL TREATED'T81,'DOLLARS/YR'/)
 303 FORMAT(//' ***** COST ESTIMATE FOR',1X,4A8,' ('I3,' UNITS)'//
    : T47,'DESIGN'T63,'OPERATING'/
    : T12,'PROCESS FLOW (PER UNIT)'T41,F11.3,' MGD',T61,F11.3,' MGD'/
    : T12,'PROCESS PARAMETER (PER UNIT)'T41,F11.2,1X,A6,T61,F11.2,
    : 1X,A6/)
 304 FORMAT(T8,'CAPITAL COST (TOTAL FOR'I3,' UNITS)'T55,'DOLLARS'//
    : T12,'CONSTRUCTION'T52,F11.0/T12,'OTHER RELATED COSTS'T52,F11.0/
    : T53,'------------'/T30,'PROCESS CAPITAL COST'T52,F11.0//
    : T8,'O&M COST (TOTAL FOR'I3,' UNITS)'T49,'CTS/1000 GAL TREATED'
    : T81,'DOLLARS/YR'/)
 305 FORMAT(T12,'ELECTRICAL ENERGY @ $'F6.3,'/KWH'T53,F10.3,T79,
    : F11.0/T12,'MAINTENANCE MATERIAL'T53,F10.3,T79,F11.0/
    : T12,'LABOR @ $'F6.3,'/HR'T53,F10.3,T79,F11.0/
    : T12,'DIESEL FUEL @ $'F6.3,'/GAL'T53,F10.3,T79,F11.0)
 306 FORMAT(T12,'NATURAL GAS @ $'F6.4,'/CU FT'T53,F10.3,T79,F11.0/
    : T12,'CHEMICALS'T53,F10.3,T79,F11.0/
    :   T53,'------------'T80,'------------'/T34,
    : 'PROCESS O&M COST'F13.3,T79,F11.0/)
 307 FORMAT(T8,'COST SUMMARY'//
    : T12,'O&M'T52,F11.3,T79,F11.0/T12,'DEBT @'
    : F5.1,' YRS AND'F5.1,' %'T52,F11.3,T79 ,F11.0/
    :  T53,'------------'T80,'------------'/
    :  T32,'PROCESS TOTAL COST'T52,F11.3,T79 ,F11.0)
 308 FORMAT(//' ***** TOTAL COST ESTIMATE FOR WATER TREATMENT PLANT'
    : ///T8,'CAPITAL COST'T55,'DOLLARS'//
    : T12,'CONSTRUCTION'T52,F11.0/
    : T12,'SITEWORK,INTERFACE PIPING,ROADS @'F5.1,' %'T52,F11.0)
 309 FORMAT(T12,'SUBSURFACE CONSIDERATIONS @'F5.1,' %'T52,F11.0)
 310 FORMAT(T12,'STANDBY POWER @'F5.1,' %'T52,F11.0)
```

TABLE 203. (Continued)

```
  311 FORMAT(T53,'-----------'/T27,'TOTAL CONSTRUCTION COST'T52,F11.0//
     : T12,'GEN CONTRACTOR OVERHEAD & PROFIT @'F5.1,' %'T55,F8.0/
     : T53,'-----------'/T42,'SUBTOTAL'T52,F11.0//
     : T12,'ENGINEERING @'F5.1,' %'T52,F11.0/T53,'-----------'/
     : T42,'SUBTOTAL'T52,F11.0/)
  312 FORMAT(T12,'LAND,'F7.2,' ACRES @ $'I6,'/ACRE'T52,F11.0)
  313 FORMAT(T12,'LEGAL,FISCAL, & ADMINISTRATIVE'T52,F11.0/
     : T12,'INTEREST DURING CONSTRUCTION'T52,F11.0/
     : T53,'-----------'/T32,'TOTAL CAPITAL COST'T52,F11.0//)
  314 FORMAT(T8,'O&M COST'T49,'CTS/1000 GAL TREATED'
     : T81,'DOLLARS/YR'//
     : T12,'ELECTRICAL ENERGY @ $'F6.3,'/KWH'T53,F10.3,T79,F11.0/
     : T12,'MAINTENANCE MATERIAL'T53,F10.3,T79,F11.0/
     : T12,'LABOR @ $'F6.3,'/HR'T53,F10.3,T79,F11.0/
     : T12,'DIESEL FUEL @ $'F6.3,'/GAL'T53,F10.3,T79,F11.0)
  315 FORMAT(T12,'NATURAL GAS @ $'F6.4,'/CU FT'T53,F10.3,T79,F11.0/
     : T12,'CHEMICALS'T53,F10.3,T79,F11.0/
     : T53,'-----------'T80,'-----------'/T36,
     : 'TOTAL O&M COST'F13.3,T79,F11.0//)
  316 FORMAT(T8,'COST SUMMARY'//
     : T12,'O&M'T52,F11.3,T79,F11.0/T12,'DEBT @'
     : F5.1,' YRS AND'F5.1,' %'T52,F11.3,T79,F11.0/
     : T53,'-----------'T80,'-----------'/
     : T40,'TOTAL COST'T52,F11.3,T79,F11.0)
  317 FORMAT(//T44,'COST SUMMARY FOR 1 WATER TREATMENT PROCESS'//)
  318 FORMAT(//T44,'COST SUMMARY FOR'I4,' WATER TREATMENT PROCESSES'//)
  319 FORMAT(T17,'PROCESS'T42,'FLOW-MGD'T64,'PROCESS PARAMETER'
     : T94,'COSTS-DOLLARS'T114,'COSTS-CTS/1000 GAL'/
     : T40,'DESIGN ACTUAL'T61,'DESIGN'T76,'OPERATING'T92,'CONSTR'
     :,'     CAPITAL'T113,'O&M     DEBT    TOTAL'/)
  320 FORMAT(1X,I2,1X,4A8,2F8.3,F11.1,1X,A6,F10.1,1X,A6,F10.0,F11.0,
     : 3F8.3)
  321 FORMAT(T7,'$',F7.2,'/TON FOR ',3A8)
  322 FORMAT(T87,'----------------------------------------------'//
     : T82,'TOTAL'T88,F10.0,F11.0,3F8.3)
  323 FORMAT(///1X,4A4,8A4/)
  324 FORMAT(T11,'CAPITAL COST FACTORS'T58,'UNIT'
     :,' COST FACTORS'T105,'COST INDEXES'//T5,'ENGINEERING(%)'T34,'='
     : F8.2,T47,'ELECTRICITY, $/KWH'T80,'='F6.2,T91,'EXCAVATION'
     :,' (ENR SKILLED LABOR)='F7.1/T5,'SITEWORK,INTERFACE PIPING(%) ='
     : F8.2,T47,'LABOR, $/HR'T80,'='F6.2,T91,'MANUFACTURED EQUIP'
     :,' (BLS #114) ='F7.1)
  325 FORMAT(T5,'SUBSURFACE CONSIDERATIONS(%) ='F8.2,T47,'DIESEL'
     :,' FUEL, $/GAL'T80,'='F6.3,T91,'CONCRETE (BLS #132)'T121,'='F7.1/
     : T5,'STANDBY POWER(%)'T34,'='F8.2,T47,'NATURAL GAS, $/CU FT'T80,
     : '='F6.4,T91,'STEEL (BLS #1017)'T121,'='F7.1/T5,'INTEREST'
     :,' RATE(%)'T34,'='F8.2,T47,'BLDNG ENERGY USE,KWH/SQ FT/YR'T80,
     : '='F6.1,T91,'LABOR(ENR SKILLED LABOR)'T121,'='F7.1)
  326 FORMAT(T5,'NUMBER OF YEARS'T34,'='F8.2,T91,'PIPES & VALVES'
     :,' (BLS #114 9   ) ='F7.1/T5,'LAND AREA, ACRES'T34,'='F8.2,T91,
     : 'ELECTRICAL & INSTR (BLS #117) ='F7.1/T5,'LAND COST, $/ACRE'
     : T34,'='F8.2,T91,'HOUSING (ENR BUILDING COST)'T121,'='F7.1/
     : T91,'PRODUCER PRICE INDEX'T121,'='F7.1)
  327 FORMAT(T47,'ENR CONSTRUCTION COST INDEX, 1967 BASE YR (USED IN'
     : ' LIEU OF ABOVE INDEXES)'T121,'='F7.1)
  328 FORMAT(T7,'$',F7.2,'/LB FOR ',3A8)
  329 FORMAT(//T56,'SITEWORK,SUBSURFACE,STNBY POWER',T88,F10.0/T66,
     : 'GEN CON OH & P,',F5.1,'%',T88,F10.0/T76,'ENGINEERING',T88,F10.0/
     : T69,'LAND,',F7.2,' ACRES',T88,F10.0/
     : T69,'LEGAL,FISCAL,ADMIN',T88,F10.0/T70,'INT DURING CONSTR',
     : T88,F10.0/T87,'------------'/T74,'TOTAL CAPITAL',T88,F10.0)
  330 FORMAT(//' TOTAL O&M:',T21,'KWH',8X,'MATERIALS,$',9X,'LABOR,HR',
     : 9X,'DIESEL,GAL',9X,'NAT GAS,CU FT',9X,'CHEMICALS,$'/
     : T16,F11.0,5X,F10.0,8X,F9.0,9X,F10.0,9X,F13.0,10X,F10.0)
  331 FORMAT(T7,'NUMBER OF UNITS =',I3)
  332 FORMAT(T7,'EMPTY BED CONTACT TIME AT DESIGN FLOW =',F5.1,' MIN')
  333 FORMAT(T7,'TDH =',F6.1,' FEET')
  334 FORMAT(T7,'ONE WAY MILES =',F6.1)
  335 FORMAT(T7,'MAKEUP LIME =',F6.1,' %')
  336 FORMAT(T7,'LOADING RATE =',F5.1,' GPM/SQ FT')
  337 FORMAT(T7,'SLUDGE CONCENTRATION =',F8.0,' MG/L')
  338 FORMAT(' PROGRAM EXIT.  CHECK THE "COST.DAT" FILE',I6,' IS NOT'
     : ' A VALID COST FACTOR NUMBER.')
  339 FORMAT(T7,'COSTS CALCULATED FOR',F7.2,' % OWNERSHIP OF REGIONAL'
     : ' FACILITY')
  341 FORMAT(T7,'TOTAL VOL.=',F8.0,' CU FT (',I4,' CONTACTORS)')
  350 FORMAT(I8,T16,F11.0,5X,F10.0,8X,F9.0,9X,
     : F10.0,9X,F13.0,10X,F10.0)
  351 FORMAT(/' PROCESS O&M')
```

TABLE 203. (Continued)

```
  352 FORMAT(/' COSTS FOR THE FOLLOWING PROCESSES HAVE BEEN'
     : ' EXTRAPOLATED.  VALID RANGES FOR INPUT DATA ARE:'//
     : T17,'PROCESS',T43,'DESIGN RANGE',T69,'YOUR INPUT',T86,
     : 'OPERATING RANGE',T114,'YOUR INPUT')
  353 FORMAT(1X,I2,1X,4A8,F9.1,' TO',F11.1,1X,A6,F11.1,F13.1,' TO',
     : F11.1,1X,A6,F11.1)
  354 FORMAT(//' PROCESS O&M',T21,'KWH',8X,'MATERIALS,$',9X,'LABOR,HR',
     : 9X,'DIESEL,GAL',9X,'NAT GAS,CU FT',9X,'CHEMICALS,$')
  370 FORMAT(' FORTRAN READ ERROR IN CARD',I5,' OF THE PROCES.DAT FILE.'
     : ' THIS CARD SHOULD CONTAIN THE WORD 'ACRES' FOLLOWED BY'/
     : ' A FLOATING POINT NUMBER OF 15 DIGITS OR LESS')
  371 FORMAT(' ERROR-CARD WITH 'ACRES=' MISSING OR MISSPELLED.'/
     : ' CHECK CARD',I5,' OF THE PROCES.DAT FILE.')
  372 FORMAT(' FORTRAN READ ERROR IN CARD',I5,' OF THE PROCES.DAT'
     : ' FILE'/' THIS CARD SHOULD CONTAIN THE INTEGER '1' '
     : 'FOLLOWED BY'/' A COMMA, THE PROCESS NUMBER AND THE PROCESS'
     : ' NAME')
  373 FORMAT(' ERROR-THIS SHOULD BE THE FIRST DATA CARD'/' OF A'
     : ' PROCESS AND SHOULD BEGIN WITH THE INTEGER '1' IN COLUMN 1'/
     : ' CHECK CARD',I5,' OF THE PROCES.DAT FILE')
  374 FORMAT(' ERROR IN CARD',I5,' OF THE PROCES,DAT FILE'/1X,I5,
     : ' IS AN INVALID PROCESS NUMBER.  PROCESSES'/' ARE NUMBERED'
     : ' 0 THRU 129 IN TABLE 2 OF THE PROGRAM MANUAL')
  375 FORMAT(' ERROR IN CARD',I5,' OF THE PROCES.DAT FILE'/' CARD'
     : ' NO.',I3,' WAS EXPECTED FOR PROCESS',I4,1X,4A8,', WHICH'
     : ' REQUIRES',I3,' CARDS OF DATA.')
  376 FORMAT(' ERROR-NOT ENOUGH DATA IN THE COST.DAT FILE.'/
     : ' THIS FILE SHOULD HAVE EITHER 28 OR 30 CARDS')
      END
      SUBROUTINE DRANGE(Y1,Y2,X)
      DIMENSION C(4),B(4),NUMUN(150),VAR(22)
      COMMON NUMUN,N/A/TOP,BOTTOM,C,B,CI
      COMMON/C/ENGR,SITE,SUBSUR,STNBY,RATE,YEARS,CLAND,ELEC,
     : HOURLY,FUEL,GASCST,ENFT,CI1,CI2,CI3,CI4,CI5,CI6,CI7,CI8,CI9,
     : CI10
      EQUIVALENCE (ENGR,VAR(1))
      IF(X.LE.0.0) GOTO 98
      GOTO 99
   98 Y1=0.0
      Y2=0.0
      GOTO 130
   99 IF(X-TOP.GT.0.0) GOTO 100
      X1=BOTTOM
      X2=2.*BOTTOM
      GOTO 110
  100 X1=TOP
      X2=(TOP+BOTTOM)/2.0
  110 C1=(C(1)+C(2)*X1+C(3)*X1**2+C(4)*X1**3)
      C2=(C(1)+C(2)*X2+C(3)*X2**2+C(4)*X2**3)
      B1= B(1)+B(2)*X1+B(3)*X1**2+B(4)*X1**3
      B2= B(1)+B(2)*X2+B(3)*X2**2+B(4)*X2**3
      ALX1=ALOG(X1)
      ALX2=ALOG(X2)
      DENOM=ALX2-ALX1
      IF(C1.GT.0.0.AND.C2.GT.0.0) GOTO 115
      Y1=0.0
      GOTO 120
  115 AC1=(ALOG(C1)*ALX2-ALOG(C2)*ALX1)/DENOM
      AC2=(ALOG(C2)-ALOG(C1))/DENOM
      Y1=EXP(AC1+AC2*ALOG(X))*NUMUN(N)*CI
  120 IF(B1.GT.0.0.AND.B2.GT.0.0) GOTO 125
      Y2=0.0
      GOTO 130
  125 AB1=(ALOG(B1)*ALX2-ALOG(B2)*ALX1)/DENOM
      AB2=(ALOG(B2)-ALOG(B1))/DENOM
      Y2=EXP(AB1+AB2*ALOG(X))*ELEC*ENFT/102.6
  130 RETURN
      END
      SUBROUTINE ORANGE(Y1,Y2,Y3,Y4,Y5,X)
      REAL M,L
      DIMENSION E(4),M(4),L(4),D(4),G(4),NUMUN(150),VAR(22)
      COMMON NUMUN,N/B/OTOP,OBOT,E,M,L,D,G,CR9
      COMMON/C/ENGR,SITE,SUBSUR,STNBY,RATE,YEARS,CLAND,ELEC,
     : HOURLY,FUEL,GASCST,ENFT,CI1,CI2,CI3,CI4,CI5,CI6,CI7,CI8,CI9,
     : CI10
      EQUIVALENCE(ENGR,VAR(1))
      F1(A1,A2)=(ALOG(A1)*ALX2-ALOG(A2)*ALX1)/DENOM
      F2(A1,A2)=(ALOG(A2)-ALOG(A1))/DENOM
      IF(X.LE.0.0) GOTO 98
      GOTO 99
```

TABLE 203. (Continued)

```
 98 Y1=0.0
    Y2=0.0
    Y3=0.0
    Y4=0.0
    Y5=0.0
    GOTO 160
 99 IF(X-OTOP.GT.0.0) GOTO 100
    X1=OBOT
    X2=2.0*OBOT
    GOTO 110
100 X1=OTOP
    X2=(OTOP+OBOT)/2.0
110 X12=X1**2
    X13=X1**3
    X22=X2**2
    X23=X2**3
    E1=E(1)+E(2)*X1+E(3)*X12+E(4)*X13
    E2=E(1)+E(2)*X2+E(3)*X22+E(4)*X23
    ALX2=ALOG(X2)
    ALX1=ALOG(X1)
    DENOM=ALX2-ALX1
    IF(E1.GT.0.0.AND.E2.GT.0.0) GOTO 115
    Y1=0.0
    GOTO 120
115 AE1=F1(E1,E2)
    AE2=F2(E1,E2)
    Y1=EXP(AE1+AE2*ALOG(X))*ELEC*NUMUN(N)
120 TM1=M(1)+M(2)*X1+M(3)*X12+M(4)*X13
    TM2=M(1)+M(2)*X2+M(3)*X22+M(4)*X23
    IF(TM1.GT.0.0.AND.TM2.GT.0.0) GOTO 125
    Y2=0.0
    GOTO 130
125 AM1=F1(TM1,TM2)
    AM2=F2(TM1,TM2)
    Y2=EXP(AM1+AM2*ALOG(X))*CR9*NUMUN(N)
130 TL1=L(1)+L(2)*X1+L(3)*X12+L(4)*X13
    TL2=L(1)+L(2)*X2+L(3)*X22+L(4)*X23
    IF(TL1.GT.0.0.AND.TL2.GT.0.0) GOTO 135
    Y3=0.0
    GOTO 140
135 AL1=F1(TL1,TL2)
    AL2=F2(TL1,TL2)
    Y3=EXP(AL1+AL2*ALOG(X))*HOURLY*NUMUN(N)
140 D1=D(1)+D(2)*X1+D(3)*X12+D(4)*X13
    D2=D(1)+D(2)*X2+D(3)*X22+D(4)*X23
    IF(D1.GT.0.0.AND.D2.GT.0.0) GOTO 145
    Y4=0.0
    GOTO 150
145 AD1=F1(D1,D2)
    AD2=F2(D1,D2)
    Y4=EXP(AD1+AD2*ALOG(X))*FUEL*NUMUN(N)
150 G1=G(1)+G(2)*X1+G(3)*X12+G(4)*X13
    G2=G(1)+G(2)*X2+G(3)*X22+G(4)*X23
    IF(G1.GT.0.0.AND.G2.GT.0.0) GOTO 155
    Y5=0.0
    GOTO 160
155 AG1=F1(G1,G2)
    AG2=F2(G1,G2)
    Y5=EXP(AG1+AG2*ALOG(X))*GASCST*NUMUN(N)
160 RETURN
    END
```

random or direct access mode. Each line of data contains 80 characters, and each process requires 5 lines of data. Therefore, the location of the first line of data of any process is given by:

$$(NP-1) \times 5 + 1$$

where NP is the number of the process shown in Table 194. For example, data for process 21, REVERSE OSMOSIS, TDS 10000 mg/L, begins at line (21-1) x 5 + 1= 101 and continues through line 105.

A copy of the CRV.DAT file is given in Table 204 and a file specification is included below.

Record	Item Description	Start Position	Format
1	Process name	1	4A8
	Design units	33	1A6
	Operating units	39	1A6
	Lower range of design curve	45	1E9.2
	Upper range of design curve	54	1E9.2
	Operating range/design range	63	1E9.2
	Integer part of chemical ratio	72	1I4
	Exponent base 10 of chemical ratio	76	1I2
	Number of chemicals used	78	1I1
	Process type for input	79	1I2
2	Coefficients - construction	1	4E10.2
	Coefficients - process energy	41	4E10.2
3	Coefficients - materials	1	4E10.2
	Coefficients - labor	41	4E10.2
4	Coefficients - diesel	1	4E10.2
	Coefficients - natural gas	41	4E10.2
5	Coefficients - building energy	1	4E10.2
	Excavation, earthwork*	41	1F5.2
	Manufactured equipment*	46	1F5.2
	Concrete*	51	1F5.2
	Steel*	56	1F5.2
	Skilled labor*	61	1F5.2
	Pipe and valves*	66	1F5.2
	Electrical & instrumentation*	71	1F5.2
	Housing*	76	1F5.2

---

*Expressed as a percent of construction cost

TABLE 204. CRV.DAT FILE

```
 1  ACT ALUM FLUORIDE REM, RFREQ 4.5CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.40E+02  1.23E+01 -2.21E-03  1.44E-06  1.24E+03  1.10E+00 -3.87E-03  4.60E-06
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 2  ACT ALUM FLUORIDE REM, RFREQ 8  CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.70E+02  7.00E+00 -2.00E-03  1.64E-06  8.84E+02  7.92E-01 -2.31E-03  2.61E-06
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 3  ACT ALUM FLUORIDE REM, RFREQ 12 CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.53E+02  5.44E+00 -3.10E-03  2.53E-06  7.50E+02  7.04E-01 -1.88E-03  2.05E-06
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 4  ACT ALUM FLUORIDE REM, RFREQ 19 CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.25E+02  4.03E+00 -3.57E-03  2.87E-06  6.38E+02  6.03E-01 -1.39E-03  1.42E-06
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 5  ACT ALUM FLUORIDE REM, RFREQ 33 CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.84E+02  2.10E+00 -1.21E-03  1.03E-06  5.60E+02  5.38E-01 -1.07E-03  1.01E-06
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 6  ACT ALUM FLUORIDE REM, RFREQ 48 CU FT CU FT  3.20E+01 7.53E+02 1.00E+00   1 02 2
     2.18E+04  4.21E+02 -7.34E-01  6.05E-04  3.79E+03  1.96E+01 -5.45E-04  0.00E-00
     2.90E+02  1.27E+00  7.92E-04 -1.04E-06  5.27E+02  5.09E-01 -9.27E-04  8.32E-07
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.53E+03  1.30E+02 -2.50E-01  3.09E-04 0.05 0.54 0.02 0.00 0.02 0.09 0.08 0.20
 7  PACKAGE LIME SOFTENING,ONE STAGEGPD   GPD     1.50E+04 1.00E+06 1.00E+00   1 04 2
     5.62E+04  2.99E-01 -4.37E-07  3.02E-13  7.71E+03  4.89E-03  4.86E-08 -2.07E-14
     1.25E+03  6.19E-03 -8.34E-09  5.20E-15  1.05E+03  9.90E-04 -1.11E-09  8.68E-16
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     9.58E+03  7.89E-02 -9.47E-08  7.05E-14 0.04 0.44 0.02 0.00 0.17 0.10 0.10 0.13
 8  PACKAGE LIME SOFTENING,TWO STAGEGPD   GPD     1.50E+04 1.00E+06 1.00E+00   1 04 2
     9.46E+04  5.06E-01 -7.69E-07  5.38E-13  1.27E+04  1.22E-02  6.99E-08 -3.31E-14
     2.07E+03  1.15E-02 -2.05E-08  1.56E-14  1.40E+03  1.09E-03 -1.28E-09  9.47E-16
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     1.86E+04  1.63E-01 -2.06E-07  1.53E-13 0.04 0.42 0.02 0.00 0.17 0.12 0.11 0.12
 9  PCKG PRESSURE FILT,2 GPM/SF,1 BWSQ FT SQ FT  3.00E-01 7.90E+01 1.00E+00   1 03 2
     2.16E+04  5.96E+03 -1.27E+02  9.12E-01  2.84E+02  1.08E+01 -1.69E-01  1.65E-03
     6.07E+01  3.79E+01 -7.71E-01  5.28E-03  1.63E+02  8.90E+00 -1.80E-01  1.26E-03
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     7.94E+03  9.21E+02  7.37E-01 -3.55E-02 0.04 0.45 0.05 0.00 0.09 0.04 0.12 0.21
10  PCKG PRESSURE FILT,2 GPM/SF,2 BWSQ FT SQ FT  3.00E-01 7.90E+01 1.00E+00   1 03 2
     2.16E+04  5.96E+03 -1.27E+02  9.12E-01  2.75E+02  1.67E+01 -8.24E-02  8.38E-04
     5.59E+01  4.72E+01 -1.02E+00  7.35E-03  1.93E+02  1.11E+01 -2.32E-01  1.64E-03
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     7.94E+03  9.21E+02  7.37E-01 -3.55E-02 0.04 0.45 0.05 0.00 0.09 0.04 0.12 0.21
```

TABLE 204. (Continued)

```
11  PCKG PRESSURE FILT,5 GPM/SF,1 BWSQ FT SQ FT  3.00E-01 7.90E+01 1.00E+00   1 03 2
       2.16E+04  5.96E+03 -1.27E+02  9.12E-01  2.84E+02  1.08E+01 -1.69E-01  1.65E-03
       6.07E+01  3.79E+01 -7.71E-01  5.28E-03  3.44E+02  8.56E+00 -1.69E-01  1.17E-03
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       7.94E+03  9.21E+02  7.37E-01 -3.55E-02 0.04 0.45 0.05 0.00 0.09 0.04 0.12 0.21
12  PCKG PRESSURE FILT,5 GPM/SF,2 BWSQ FT SQ FT  3.00E-01 7.90E+01 1.00E+00   1 03 2
       2.16E+04  5.96E+03 -1.27E+02  9.12E-01  2.75E+02  1.67E+01 -8.24E-02  8.38E-04
       5.59E+01  4.72E+01 -1.02E+00  7.35E-03  3.75E+02  1.08E+01 -2.20E-01  1.54E-03
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       7.94E+03  9.21E+02  7.37E-01 -3.55E-02 0.04 0.45 0.05 0.00 0.09 0.04 0.12 0.21
13  PCKG GRAVITY FILT,2 GPM/SF,1 BW SQ FT SQ FT  6.30E+00 2.25E+02 1.00E+00   1 01 2
       2.75E+04  1.00E+03 -2.34E+00  4.92E-03  1.70E+02  4.47E+00  3.15E-02 -7.86E-05
       4.43E+02  1.30E+01 -8.48E-02  1.86E-04  2.31E+02  3.74E+00 -2.23E-02  5.00E-05
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.49E+04  7.52E+02 -1.66E+00  3.89E-03 0.06 0.25 0.08 0.00 0.07 0.13 0.12 0.29
14  PCKG GRAVITY FILT,2 GPM/SF,2 BW SQ FT SQ FT  6.30E+00 2.25E+02 1.00E+00   1 01 2
       2.75E+04  1.00E+03 -2.34E+00  4.92E-03  1.01E+02  1.57E+01  5.21E-03 -2.75E-05
       5.16E+02  1.00E+01 -2.19E-02  0.00E-00  2.76E+02  4.55E+00 -2.78E-02  6.33E-05
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.49E+04  7.52E+02 -1.66E+00  3.89E-03 0.06 0.25 0.08 0.00 0.07 0.13 0.12 0.29
15  PCKG GRAVITY FILT,5 GPM/SF,1 BW SQ FT SQ FT  6.30E+00 2.25E+02 1.00E+00   1 01 2
       2.75E+04  1.00E+03 -2.34E+00  4.92E-03  1.70E+02  4.47E+00  3.15E-02 -7.86E-05
       4.43E+02  1.30E+01 -8.48E-02  1.86E-04  4.12E+02  3.65E+00 -2.14E-02  4.73E-05
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.49E+04  7.52E+02 -1.66E+00  3.89E-03 0.06 0.25 0.08 0.00 0.07 0.13 0.12 0.29
16  PCKG GRAVITY FILT,5 GPM/SF,2 BW SQ FT SQ FT  6.30E+00 2.25E+02 1.00E+00   1 01 2
       2.75E+04  1.00E+03 -2.34E+00  4.92E-03  1.01E+02  1.57E+01  5.21E-03 -2.75E-05
       6.75E+02  1.32E+01 -8.13E-02  1.70E-04  4.57E+02  4.47E+00 -2.70E-02  6.09E-05
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.49E+04  7.52E+02 -1.66E+00  3.89E-03 0.06 0.25 0.08 0.00 0.07 0.13 0.12 0.29
17  PCKG  PRESSURE CARBON CONTACTORSCU FT CU FT  1.80E+00 7.85E+02 1.00E+00   1 01 2
       1.81E+04  7.20E+02 -1.67E+00  1.36E-03  8.56E+00  1.61E-01  5.86E-04 -5.17E-07
       7.92E+01  4.78E+00 -1.05E-02  8.41E-06  1.93E+02  1.53E+00 -3.62E-03  2.89E-06
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.09E+04  2.21E+02 -2.52E-01  1.18E-04 0.04 0.38 0.06 0.00 0.11 0.04 0.12 0.25
18  PCKG  GRAVITY CARBON CONTACTORS CU FT CU FT  3.15E+01 1.13E+03 1.00E+00   1 01 2
       2.72E+04  2.39E+02 -9.84E-02  4.25E-05  1.67E-02  3.17E-01  1.12E-05 -1.53E-08
       3.70E+02  2.41E+00 -2.47E-03  1.44E-06  2.73E+02  1.07E+00 -1.51E-03  7.31E-07
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.49E+04  1.49E+02 -6.63E-02  3.12E-05 0.04 0.31 0.07 0.00 0.08 0.11 0.12 0.27
19  REVERSE OSMOSIS, TDS 5000 MG/L  GPD   GPD    2.50E+03 1.00E+06 1.00E+00   1 03 2
       2.77E+04  1.14E+00 -8.36E-07  4.99E-13  9.23E+03  3.65E+00 -1.24E-06  6.62E-13
       7.85E+01  1.09E-01 -3.97E-08  1.28E-14  3.29E+02  3.42E-03 -6.72E-09  4.10E-15
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.53E+04  1.07E-01  7.10E-08 -3.91E-14 0.00 0.72 0.00 0.00 0.02 0.00 0.09 0.17
20  REVERSE OSMOSIS, TDS 8000 MG/L  GPD   GPD    2.50E+03 1.00E+06 1.00E+00   1 03 2
       2.77E+04  1.14E+00 -8.36E-07  4.99E-13  9.26E+03  3.62E+00  1.36E-06 -1.15E-12
       7.78E+01  1.10E-01 -2.57E-08  2.24E-15  3.27E+02  3.59E-03 -6.76E-09  4.06E-15
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.53E+04  1.07E-01  7.10E-08 -3.91E-14 0.00 0.72 0.00 0.00 0.02 0.00 0.09 0.17
```

TABLE 204. (Continued)

```
21  REVERSE OSMOSIS, TDS 10000 MG/L GPD   GPD    2.50E+03 1.00E+06 1.00E+00   1 03 2
     2.77E+04  1.14E+00 -8.36E-07  4.99E-13  8.78E+03  3.74E+00  3.83E-06 -2.99E-12
     7.42E+01  1.11E-01 -1.37E-08 -7.35E-15  3.21E+02  4.09E-03 -7.66E-09  4.56E-15
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     1.53E+04  1.07E-01  7.10E-08 -3.91E-14 0.00 0.72 0.00 0.00 0.02 0.00 0.09 0.17
22  REVERSE OSMOSIS, LOW PRESSURE   GPD   GPD    2.50E+03 1.00E+06 1.00E+00   1 03 2
     2.77E+04  1.14E+00 -8.36E-07  4.99E-13  5.36E+03  1.91E+00 -6.83E-07  3.80E-13
     7.85E+01  1.09E-01 -3.97E-08  1.28E-14  3.29E+02  3.42E-03 -6.72E-09  4.10E-15
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     1.53E+04  1.07E-01  7.10E-08 -3.91E-14 0.00 0.72 0.00 0.00 0.02 0.00 0.09 0.17
23  GAS FEED CHLOR., TO 40 LB/DAY   LB/DAYLB/DAY 1.00E+00 4.00E+01 1.00E+00   1 01 1
     1.43E+04  2.64E-10  1.59E-11  2.31E-13  1.40E+03  5.27E+00  7.17E-01  0.00E-00
     2.43E+02  5.61E-01 -1.58E-03  0.00E-00  1.83E+02  8.69E-14 -6.40E-15  1.08E-16
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     7.63E+03  3.35E-12 -2.47E-13  4.19E-15 0.07 0.29 0.02 0.00 0.03 0.03 0.12 0.44
24  GAS FEED CHLOR., 40 TO 80 LB/DAYLB/DAYLB/DAY 4.00E+01 8.00E+01 1.00E+00   1 01 1
     1.51E+04 -7.52E-10  4.02E-11 -1.70E-13  1.96E+02  6.79E+01 -1.35E-01  7.00E-04
     2.80E+02 -4.68E-11  1.60E-12 -8.97E-15  1.83E+02 -3.06E-11  1.04E-12 -5.87E-15
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     7.63E+03 -1.27E-09  4.34E-11 -2.45E-13 0.06 0.32 0.02 0.00 0.03 0.03 0.11 0.43
25  HYPOCHLORITE SOL. CHLORINATION  LB/DAYLB/DAY 1.00E+00 1.00E+02 1.00E+00   1 01 1
     1.23E+04 -5.48E-12  5.78E-13 -2.13E-15  1.75E+03 -1.52E-17 -3.79E-22  8.68E-29
     2.45E+02 -1.86E-18 -5.44E-23  1.31E-29  1.80E+02 -1.50E-18 -4.01E-23  8.83E-30
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     7.63E+03 -7.26E-17 -1.69E-21  3.87E-28 0.08 0.18 0.02 0.00 0.03 0.03 0.15 0.51
26  ULTRAVIOLET LIGHT DISINFECTION  GPD   GPD    5.76E+03 1.01E+06 1.00E+00   1 00 1
     7.20E+03  9.69E-02 -1.23E-07  6.36E-14  4.94E+02  5.42E-02 -1.96E-08  1.04E-14
     1.06E+02  6.66E-03 -5.50E-09  3.44E-15  6.77E+01  4.04E-05 -4.50E-11  2.08E-17
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     5.47E+03  4.70E-02 -6.63E-08  3.57E-14 0.00 0.35 0.06 0.00 0.05 0.06 0.03 0.45
27  PACKAGE ULTRAFILTRATION PLANTS  SQ FT SQ FT  3.00E+01 1.43E+04 1.00E+00   1 00 1
     1.42E+04  6.89E+01 -5.44E-03  2.33E-07  3.17E+03  4.55E+00 -4.04E-05  0.00E-00
     4.95E+01  3.94E+00  5.94E-05 -3.08E-09  3.55E+02  4.46E-02  1.91E-06 -9.74E-11
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     7.89E+03  1.56E+01 -8.73E-04  5.63E-08 0.03 0.51 0.05 0.00 0.10 0.02 0.11 0.18
28  COVERED SLOW SAND FILTERS       SQ FT SQ FT  1.08E+03 1.60E+04 1.00E+00   1 00 1
     7.11E+04  9.24E+01 -2.96E-03  1.32E-07  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     8.20E+01  6.21E-01 -4.31E-05  1.65E-09  1.41E+02  4.71E-02  3.00E-06 -1.50E-10
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     8.89E+04  4.09E+01 -4.11E-03  1.38E-07 0.08 0.12 0.28 0.00 0.32 0.05 0.09 0.06
29  UNCOVERED SLOW SAND FILTERS     SQ FT SQ FT  1.08E+03 1.60E+04 1.00E+00   1 00 1
     7.95E+04  4.48E+01 -3.93E-03  1.65E-07  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     2.15E+02  6.63E-02 -3.53E-06  1.66E-10  1.76E+02  6.10E-02  2.26E-06 -1.35E-10
     2.00E+01  1.87E-02 -1.41E-06  3.96E-11  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     8.89E+04  4.09E+01 -4.11E-03  1.38E-07 0.09 0.50 0.07 0.00 0.14 0.04 0.06 0.10
30  PACKAGE HIGH SERVICE PUMPING STAGPD   GPD    4.32E+04 2.88E+06 1.00E+00   1 00 1
     9.78E+03  2.15E-02 -5.93E-09  7.23E-16 -2.58E+03  3.16E-01 -2.32E-08  2.94E-15
     5.91E+01  8.20E-05 -5.55E-12  0.00E-00  9.54E+01  1.14E-04 -8.01E-11  1.68E-17
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.68 0.00 0.00 0.15 0.06 0.11 0.00
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TABLE 204. (Continued)

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31  PACKAGE RAW WATER PUMPING STA.  GPD   GPD    2.88E+04 1.01E+06 1.00E+00   1 00 1
     1.90E+04  1.83E-02 -8.09E-09  6.92E-15 -2.49E+01  8.07E-02  2.86E-10 -4.95E-16
     6.24E+01  2.85E-04 -3.43E-10  1.83E-16  4.83E+01  7.66E-05 -3.04E-11  2.54E-17
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.37 0.32 0.03 0.00 0.16 0.08 0.04 0.00
32  ELECTRODIALYSIS, TDS 1000 MG/L  GPD   GPD    1.50E+03 1.00E+06 1.00E+00   1 02 2
     2.36E+04  1.83E+00 -4.41E-06  3.47E-12 -2.94E+01  1.75E+00 -1.40E-09 -1.58E-15
     3.95E+01  6.67E-02 -5.82E-08  5.53E-14  3.71E+02  1.17E-03 -4.46E-10  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     1.16E+04  4.34E-01 -9.37E-07  7.52E-13 0.03 0.72 0.01 0.00 0.02 0.00 0.07 0.15
33  ELECTRODIALYSIS, TDS 2000 MG/L  GPD   GPD    1.50E+03 1.00E+06 1.00E+00   1 02 2
     2.36E+04  1.83E+00 -4.41E-06  3.47E-12 -2.84E+01  2.49E+00 -2.03E-08  1.40E-14
     2.09E+01  7.92E-02 -6.61E-08  6.40E-14  4.07E+02  1.29E-03 -5.05E-10  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     1.16E+04  4.34E-01 -9.37E-07  7.52E-13 0.03 0.72 0.01 0.00 0.02 0.00 0.07 0.15
34  ELECTRODIALYSIS, TDS 3000 MG/L  GPD   GPD    1.50E+03 1.00E+06 1.00E+00   1 02 2
     2.36E+04  1.83E+00 -4.41E-06  3.47E-12 -1.98E+01  3.21E+00 -4.22E-09  8.14E-16
    -4.39E+00  9.67E-02 -9.88E-08  9.18E-14  4.48E+02  1.42E-03 -5.56E-10  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     1.16E+04  4.34E-01 -9.37E-07  7.52E-13 0.03 0.72 0.01 0.00 0.02 0.00 0.07 0.15
35  EROSION FEED CHLOR., GRAVITY    LB/DAYLB/DAY 1.00E-01 6.00E+00 1.00E+00   1 01 1
     6.97E+04 -1.48E-10  2.73E-10 -1.01E-12  5.32E-01  2.15E+02  9.77E-01 -1.08E-01
     6.66E+00  3.87E+00 -9.25E-01  7.99E-02  5.16E+01  1.05E+02 -2.58E-01  3.49E-02
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.82 0.00 0.00 0.12 0.06 0.00 0.00
36  EROSION FEED CHLOR., VENTURI    LB/DAYLB/DAY 1.00E-01 6.00E+00 1.00E+00   1 01 1
     8.88E+04 -1.84E-10  3.48E-10 -1.26E-12  5.32E-01  2.15E+02  9.77E-01 -1.08E-01
     6.66E+00  3.87E+00 -9.25E-01  7.99E-02  5.16E+01  1.05E+02 -2.58E-01  3.49E-02
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.73 0.00 0.00 0.18 0.09 0.00 0.00
37  EROSION FEED CHLOR., CHEM PUMP  LB/DAYLB/DAY 1.00E-01 6.00E+00 1.00E+00   1 01 1
     1.07E+05 -2.23E-10  4.11E-10 -1.51E-12  5.32E-01  2.15E+02  9.77E-01 -1.08E-01
     6.66E+00  3.87E+00 -9.25E-01  7.99E-02  5.16E+01  1.05E+02 -2.58E-01  3.49E-02
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.65 0.00 0.00 0.15 0.08 0.04 0.08
38  CHLORINE DIOXIDE GEN. & FEED EQ.LB/DAYLB/DAY 1.00E-01 4.38E+01 1.00E+00   1 03 2
     2.57E+04 -2.47E-10  1.31E-11  2.91E-13  7.64E+03  5.28E+02 -5.59E+00  0.00E-00
     3.13E+02  1.82E+01 -6.36E-01  7.99E-03  1.69E+02  4.82E+00 -3.66E-02  8.80E-03
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     9.47E+03  7.58E-12 -4.63E-13  6.73E-15 0.03 0.35 0.01 0.00 0.13 0.10 0.06 0.32
39  OZONE GENERATION,FEED-AIR,5 KWH LB/DAYLB/DAY 5.00E+00 1.10E+02 1.00E+00   1 00 1
     8.37E+04  1.38E+03  1.61E+00 -3.04E-02 -4.79E+01  1.83E+03 -1.55E-01  1.19E-03
     1.52E+03  7.92E+01 -4.95E-01  2.52E-03  5.29E+02  3.57E+00 -1.16E-02  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     3.59E+04  1.33E+02  3.12E-03  0.00E-00 0.02 0.40 0.00 0.00 0.20 0.05 0.16 0.17
40  OZONE GENERATION,FEED-AIR,8 KWH LB/DAYLB/DAY 5.00E+00 1.10E+02 1.00E+00   1 00 1
     8.37E+04  1.38E+03  1.61E+00 -3.04E-02  5.80E+01  2.91E+03  6.68E-01 -5.03E-03
     1.52E+03  7.92E+01 -4.95E-01  2.52E-03  5.29E+02  3.57E+00 -1.16E-02  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     3.59E+04  1.33E+02  3.12E-03  0.00E-00 0.02 0.40 0.00 0.00 0.20 0.05 0.16 0.17
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TABLE 204. (Continued)

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41  OZONE GENERATION,FEED-02,3.5 KWHLB/DAYLB/DAY 1.00E+01 2.20E+02 1.00E+00   1 00 1
     7.72E+04  6.02E+02  9.13E-01 -5.39E-03 -1.00E+01  1.28E+03 -1.28E-01  4.81E-04
     1.51E+03  2.58E+02 -1.94E-01  5.46E-04  5.29E+02  1.79E+00 -2.89E-03  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     3.59E+04  6.63E+01  7.79E-04  0.00E-00 0.03 0.36 0.00 0.00 0.21 0.05 0.17 0.18
42  OZONE CONTACTORS                  GAL   GAL    2.00E+03 1.50E+04 1.00E+00   1 00 1
     1.11E+04  2.59E+00 -1.34E-04  4.18E-09  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.23 0.56 0.00 0.00 0.21 0.00 0.00
43  PACKAGE VACUUM DIATOMITE FILTERSSQ FT SQ FT  3.00E+01 7.20E+02 1.00E+00   1 02 2
     2.35E+04  3.79E+02 -7.56E-01  5.79E-04  5.10E+03  1.48E+02 -9.06E-02  0.00E-00
     7.56E+01  2.30E+00 -5.17E-03  4.05E-06  6.54E+02  2.44E+00 -1.28E-03  3.09E-06
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     1.88E+04  3.44E+01  9.05E-02 -9.26E-05 0.05 0.35 0.07 0.00 0.09 0.06 0.12 0.26
44  PACKAGE PRESSURE DIATOMITE FILT.SQ FT SQ FT  1.92E+01 7.50E+02 1.00E+00   1 01 2
     3.38E+04  3.50E+02 -2.00E-01  1.36E-04  2.80E+01  7.26E+01 -2.42E-02  2.62E-05
     1.08E+02  1.91E+00 -3.42E-03  2.42E-06  6.34E+02  2.80E+00 -3.77E-03  5.41E-06
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     1.69E+04  1.23E+02 -2.48E-01  2.19E-04 0.04 0.40 0.06 0.00 0.13 0.08 0.09 0.20
45  DIFFUSED AERATION, 2.6 SCFM, 7FTGAL   GAL    2.00E+02 7.00E+03 1.00E+00   1 00 1
     1.93E+03  6.06E+00 -8.68E-04  8.26E-08 -9.14E+01  1.52E+01 -4.19E-04  7.42E-09
     5.38E+01  4.51E-02  2.21E-05 -1.58E-09  6.41E+01  6.77E-03  4.46E-07 -6.80E-11
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.03 0.57 0.04 0.00 0.18 0.09 0.09 0.00
46  DIFFUSED AERATION, 2.6 SCFM,12FTGAL   GAL    4.00E+02 1.40E+04 1.00E+00   1 00 1
     2.59E+03  3.90E+00 -2.90E-04  1.27E-08 -2.92E+01  1.25E+01 -1.38E-04 -3.55E-10
     5.38E+01  2.26E-02  5.53E-06 -1.97E-10  6.41E+01  3.38E-03  1.11E-07 -8.49E-12
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.02 0.61 0.03 0.00 0.18 0.09 0.07 0.00
47  DIFFUSED AERATION, 5.3 SCFM, 7FTGAL   GAL    2.00E+02 7.00E+03 1.00E+00   1 00 1
     2.57E+03  4.93E+00  9.82E-04 -1.18E-07  1.21E+01  2.99E+01 -5.94E-04 -8.59E-09
     1.21E+01  2.28E-01  2.57E-06  0.00E-00  6.03E+01  1.97E-02 -1.60E-06  3.09E-11
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.02 0.60 0.03 0.00 0.18 0.09 0.08 0.00
48  DIFFUSED AERATION, 5.3 SCFM,12FTGAL   GAL    4.00E+02 1.40E+04 1.00E+00   1 00 1
     3.12E+03  3.41E+00  1.56E-04 -1.11E-08 -5.59E+01  2.51E+01 -2.83E-04 -1.84E-10
     1.21E+01  1.14E-01  6.43E-07  0.00E-00  6.03E+01  9.83E-03 -4.01E-07  3.86E-12
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.02 0.62 0.02 0.00 0.19 0.09 0.06 0.00
49  DIFFUSED AERATION, 7.9 SCFM, 7FTGAL   GAL    2.00E+02 7.00E+03 1.00E+00   1 00 1
     2.47E+03  7.49E+00  6.99E-04 -7.92E-08 -6.11E+01  4.50E+01 -9.61E-04 -7.22E-09
     4.97E+01  2.28E-01  4.62E-05 -4.08E-09  6.46E+01  2.80E-02 -4.59E-06  3.18E-10
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.02 0.61 0.02 0.00 0.19 0.09 0.07 0.00
50  DIFFUSED AERATION, 7.9 SCFM,12FTGAL   GAL    4.00E+02 1.40E+04 1.00E+00   1 00 1
     3.11E+03  4.63E+00  9.84E-05 -7.22E-09 -4.91E+01  3.75E+01 -3.87E-04 -2.45E-09
     4.97E+01  1.14E-01  1.16E-05 -5.10E-10  6.46E+01  1.40E-02 -1.15E-06  3.98E-11
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.01 0.62 0.02 0.00 0.19 0.10 0.06 0.00
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TABLE 204. (Continued)

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51  WATER WELLS, 250 FT DEPTH       GPD   GPD    1.44E+05 1.01E+06 1.00E+00    1 00 1
     2.85E+04  7.40E-02 -7.96E-08  4.70E-14  4.07E+02  3.03E-01  6.96E-09 -4.91E-15
     7.56E+02  9.81E-04  6.47E-10 -4.99E-16  4.25E+02  1.72E-04  3.10E-12 -2.39E-18
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.03 0.24 0.03 0.00 0.30 0.13 0.18 0.09
52  WATER WELLS, 500 FT DEPTH       GPD   GPD    1.44E+05 1.01E+06 1.00E+00    1 00 1
     3.92E+04  1.90E-01 -3.78E-07  2.78E-13  2.95E+03  6.66E-01  4.69E-08 -2.82E-14
     7.78E+02  4.06E-03 -5.46E-09  2.91E-15  4.75E+02  1.72E-04  3.10E-12 -2.39E-18
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.02 0.19 0.09 0.00 0.37 0.14 0.14 0.05
53  FILTER MEDIA, RAPID SAND        SQ FT SQ FT  2.00E+00 3.50E+02 1.00E+00    1 00 1
     8.18E+01  6.52E+01 -2.17E-01  4.37E-04  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00
54  FILTER MEDIA, DUAL MEDIA        SQ FT SQ FT  2.00E+00 3.50E+02 1.00E+00    1 00 1
     1.68E+02  9.36E+01 -3.02E-01  6.11E-04  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00
55  FILTER MEDIA, MIXED MEDIA       SQ FT SQ FT  2.00E+00 3.50E+02 1.00E+00    1 00 1
     3.95E+02  1.66E+02 -8.39E-01  1.70E-03  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00
56  MULTI-TECH SYSTEM               GPD   GPD    6.50E+04 1.10E+06 1.00E+00    1 02 2
     7.03E+04  3.07E-01 -1.23E-07  4.82E-14  8.35E+02  1.01E-02 -6.74E-09  1.15E-15
     5.02E+02  6.68E-03  8.41E-09 -6.34E-15  4.93E+02  1.39E-03 -1.29E-09  6.05E-16
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     2.40E+04  2.04E-01 -2.90E-08 -1.35E-14 0.03 0.50 0.01 0.00 0.15 0.04 0.07 0.20
57  MULTI-TECH SYSTEM PLUS CARBON   GPD   GPD    6.50E+04 1.10E+06 1.00E+00    1 03 2
     7.57E+04  4.47E-01 -2.09E-07  8.77E-14  8.35E+02  1.01E-02 -6.74E-09  1.15E-15
     6.71E+02  6.16E-03  1.23E-08 -8.34E-15  5.46E+02  1.47E-03 -1.26E-09  5.67E-16
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     3.55E+04  2.43E-01  1.18E-07 -1.26E-13 0.03 0.51 0.01 0.00 0.15 0.04 0.07 0.19
58  BELOW GROUND CONCRETE CLEARWELL GAL   GAL    5.00E+03 5.00E+05 1.00E+00    1 00 1
     8.80E+03  9.28E-01 -3.56E-06  5.18E-12  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.25 0.00 0.67 0.01 0.00 0.00 0.07 0.00
59  GROUND-LEVEL STEEL CLEARWELLS   GAL   GAL    1.00E+03 1.00E+06 1.00E+00    1 00 1
     7.62E+03  6.30E-01 -1.26E-06  8.12E-13  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.00 0.25 0.65 0.00 0.00 0.10 0.00
60  PACKAGE FLOCCULATOR/CLARIFIER   SQ FT SQ FT  7.00E+01 7.40E+02 1.00E+00    1 02 2
     2.59E+04  4.73E+02 -9.15E-01  8.08E-04  3.63E+03 -1.04E+01  7.23E-02 -5.50E-05
     1.33E+02  6.51E-01 -8.13E-04  1.05E-06  7.00E+01  1.04E+00 -2.06E-03  1.56E-06
     0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
     1.05E+04  2.34E+02 -2.23E-01  2.11E-04 0.05 0.48 0.07 0.00 0.08 0.03 0.03 0.26
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TABLE 204. (Continued)

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 61  CONTACT BASINS                  GAL    GAL    1.20E+03 4.20E+04 1.00E+00   1 00 1
      1.93E+03  2.87E-01  6.50E-05 -8.67E-10  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      6.23E+01  6.09E-03  2.31E-07 -2.57E-12  7.10E+00  2.36E-03 -1.13E-08 -2.27E-13
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.03 0.71 0.05 0.00 0.12 0.09 0.00 0.00
 62  PELLET FEED CHLORINATORS        LB/DAYLB/DAY 1.00E-01 1.30E+01 1.00E+00   1 01 1
      8.47E+02 -7.93E-13  2.67E-13 -1.10E-14  3.81E-01  1.60E+01  2.82E-01 -1.39E-02
      1.23E+01  3.77E+00  2.03E-01 -1.55E-02  5.22E+01  1.77E+01 -1.21E-01  1.02E-02
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.73 0.00 0.00 0.00 0.18 0.00 0.09 0.00
 63  SLUDGE DISPOSAL TO SANIT. SEWERSMG/L  MG/L   1.00E+03 1.00E+05 1.00E+00   1 0011
      3.64E+03  2.94E+00 -1.25E-07  9.60E-13  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      2.00E+04  0.00E-00  0.00E-00  0.00E-00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
 64  ON SITE HYPOCHLORITE GENERATION LB/DAYLB/DAY 2.00E+01 1.00E+02 1.00E+00   1 01 2
      1.37E+04  2.01E+02 -1.27E+00  5.08E-03 -1.84E+01  9.19E+02 -2.67E-01  2.03E-03
      1.94E+02  2.23E+01 -1.30E-01  3.48E-04  2.35E+01  5.31E+00 -1.22E-03 -1.06E-04
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
      9.42E+03  7.84E+00  2.47E-01  0.00E-00 0.00 0.65 0.00 0.00 0.06 0.01 0.01 0.27
 65  CONVEN. PCKG COMPL,2 GPM/SF,1 BWSQ FT SQ FT  2.00E+00 1.50E+02 1.00E+00   1 02 2
      4.83E+04  3.00E+03 -8.21E+00  0.00E-00  2.54E+02  1.29E+02 -1.16E+00  3.65E-03
      5.25E+02  3.99E+01 -1.08E-01  0.00E-00  3.97E+02  1.47E+01 -1.06E-01  3.56E-04
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.79E+04  1.59E+03 -4.68E+00  0.00E-00 0.03 0.46 0.02 0.00 0.16 0.09 0.05 0.19
 66  CONVEN. PCKG COMP.,2 GPM/ST,2 BWSQ FT SQ FT  2.00E+00 1.50E+02 1.00E+00   1 02 2
      4.83E+04  3.00E+03 -8.21E+00  0.00E-00  2.45E+02  1.33E+02 -1.17E+00  3.70E-03
      6.93E+02  4.75E+01 -1.20E-01  0.00E-00  4.16E+02  1.55E+01 -1.17E-01  4.02E-04
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.79E+04  1.59E+03 -4.68E+00  0.00E-00 0.03 0.46 0.02 0.00 0.16 0.09 0.05 0.19
 67  CONVEN. PCKG COMPL,5 GPM/SF,1 BWSQ FT SQ FT  2.00E+00 1.50E+02 1.00E+00   1 02 2
      4.83E+04  3.00E+03 -8.21E+00  0.00E-00  2.54E+02  1.29E+02 -1.16E+00  3.65E-03
      5.25E+02  3.99E+01 -1.08E-01  0.00E-00  5.39E+02  2.18E+01 -1.91E-01  6.15E-04
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.79E+04  1.59E+03 -4.68E+00  0.00E-00 0.03 0.46 0.02 0.00 0.16 0.09 0.05 0.19
 68  CONVEN. PCKG COMPL,5 GPM/SF,2 BWSQ FT SQ FT  2.00E+00 1.50E+02 1.00E+00   1 02 2
      4.83E+04  3.00E+03 -8.21E+00  0.00E-00  2.45E+02  1.33E+02 -1.17E+00  3.70E-03
      6.93E+02  4.75E+01 -1.20E-01  0.00E-00  6.01E+02  1.50E+01 -1.07E-01  3.58E-04
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.79E+04  1.59E+03 -4.68E+00  0.00E-00 0.03 0.46 0.02 0.00 0.16 0.09 0.05 0.19
 69  NEPTUNE MICROFLOC TRIDENT, 1 BW GPD   GPD    2.52E+05 1.01E+06 1.00E+00   1 03 2
     -2.60E+04  8.35E-01 -1.03E-06  4.58E-13  7.03E+02  1.56E-03  4.93E-11 -3.26E-17
     -7.63E+02  1.39E-02 -1.73E-08  7.63E-15 -3.78E+02  5.75E-03 -7.68E-09  3.52E-15
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.75E+04  2.37E-01 -2.22E-07  9.16E-14 0.03 0.49 0.01 0.00 0.15 0.07 0.07 0.18
 70  NEPTUNE MICROFLOC TRIDENT, 2 BW GPD   GPD    2.52E+05 1.01E+06 1.00E+00   1 03 2
     -2.58E+04  8.35E-01 -1.03E-06  4.56E-13  8.05E+02  2.35E-03  7.39E-11 -4.89E-17
     -6.96E+02  1.53E-02 -1.76E-08  7.28E-15 -2.11E+02  4.77E-03 -5.72E-09  2.41E-15
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      1.33E+04  2.66E-01 -2.79E-07  1.24E-13 0.03 0.49 0.01 0.00 0.15 0.07 0.07 0.18
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TABLE 204. (Continued)

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 71  BASIC POLYMER FEED, ONE TANK    LB/DAYLB/DAY 6.00E-01 1.04E+01 1.00E+00   1 01 1
       1.61E+03  4.06E+02 -1.29E+01  0.00E-00  1.89E+02  5.11E+01 -2.43E+00  0.00E-00
       2.68E+01  2.47E+00 -3.30E-02  0.00E-00  2.42E+02  1.20E+01  2.96E-01  0.00E-00
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.81 0.00 0.00 0.07 0.07 0.05 0.00
 72  BASIC POLYMER FEED, TWO TANKS   LB/DAYLB/DAY 6.00E-01 1.04E+01 1.00E+00   1 01 1
       2.29E+03  5.28E+02 -1.65E+01  0.00E-00  1.89E+02  5.11E+01 -2.43E+00  0.00E-00
       2.68E+01  2.47E+00 -3.30E-02  0.00E-00  2.42E+02  1.20E+01  2.96E-01  0.00E-00
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.65 0.00 0.00 0.11 0.07 0.04 0.13
 73  AUTOMATIC POLYMER FEED SYSTEM   LB/DAYLB/DAY 5.00E-01 1.00E+01 1.00E+00   1 01 1
       1.95E+03  1.89E-12  2.11E-11  2.69E-12  4.08E+02  1.09E+02  4.34E-02  0.00E-00
       9.18E+01  6.78E+00 -2.01E-01  0.00E-00  5.00E+01  4.62E-14  5.39E-13  6.84E-14
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.49 0.00 0.00 0.13 0.13 0.25 0.00
 74  SAND DRYING BEDS,5 CLEANINGS/YR SQ FT SQ FT  2.00E+02 2.00E+03 1.00E+00   1 00 1
       1.97E+03  1.77E+00  3.49E-03 -1.03E-06  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      -1.26E+01  2.21E-01 -9.46E-05  2.68E-08 -4.62E+00  8.21E-02 -4.91E-05  1.40E-08
      -7.45E+00  1.27E-01 -7.71E-05  2.20E-08  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.09 0.00 0.34 0.03 0.41 0.13 0.00 0.00
 75  SAND DRYING BEDS,8 CLEANINGS/YR SQ FT SQ FT  2.00E+02 2.00E+03 1.00E+00   1 00 1
       1.97E+03  1.77E+00  3.49E-03 -1.03E-06  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      -8.06E+00  3.03E-01 -9.95E-05  2.84E-08 -7.39E+00  1.31E-01 -7.85E-05  2.24E-08
      -1.11E+01  1.97E-01 -1.18E-04  3.36E-08  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.09 0.00 0.34 0.03 0.41 0.13 0.00 0.00
 76  SAND DRYING BEDS,15 CLEANINGS/YRSQ FT SQ FT  2.00E+02 2.00E+03 1.00E+00   1 00 1
       1.97E+03  1.77E+00  3.49E-03 -1.03E-06  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      -1.72E+01  5.76E-01 -1.94E-04  5.47E-08 -1.39E+01  2.46E-01 -1.47E-04  4.20E-08
      -2.13E+01  3.73E-01 -2.24E-04  6.40E-08  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.09 0.00 0.34 0.03 0.41 0.13 0.00 0.00
 77  BASIC CHEMICAL FEED,ALL BUT LIMELB/DAYLB/DAY 1.00E+01 1.00E+03 1.00E+00   1 01 1
       9.83E+02  1.84E+01 -3.31E-02  2.04E-05  1.40E+02  1.65E+00 -7.83E-04  0.00E-00
       2.36E+01  1.84E-01 -8.48E-05  0.00E-00  2.07E+02  1.32E+00 -2.34E-03  1.64E-06
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.43 0.00 0.00 0.09 0.08 0.06 0.34
 78  BASIC CHEMICAL FEED, HYDR LIME  LB/DAYLB/DAY 1.00E+01 1.00E+03 1.00E+00   1 01 1
       9.83E+02  1.84E+01 -3.31E-02  2.04E-05  1.72E+03  1.51E+01 -7.24E-03  0.00E-00
       2.22E+01  3.57E-01 -5.62E-04  2.96E-07  2.07E+02  1.32E+00 -2.34E-03  1.64E-06
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.43 0.00 0.00 0.09 0.08 0.06 0.34
 79  DRY CHEMICAL FEEDER SYSTEM      CF/DAYLB/DAY 1.70E+00 3.30E+01 3.03E+01   1 01 1
       3.05E+03  1.96E+02 -8.06E+00  1.16E-01  3.26E+03  1.42E-13 -1.14E-16  1.28E-18
       5.62E+01  6.57E-02 -1.72E-05  0.00E-00  4.31E+01  7.77E-01 -4.30E-04  2.81E-07
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.65 0.00 0.00 0.06 0.04 0.06 0.19
 80  SULFURIC ACID FEED SYSTEMS      LB/DAYLB/DAY 8.00E-01 8.34E+02 1.00E+00   1 01 1
       1.17E+03  1.22E+01 -2.41E-02  1.84E-05  4.08E+01  1.11E-01  6.78E-04 -3.89E-07
       3.38E+01  3.35E-01 -6.61E-04  4.45E-07  1.33E+02  2.57E-01 -1.10E-04  0.00E-00
       0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.19 0.03 0.00 0.00 0.18 0.37 0.05 0.18
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TABLE 204. (Continued)

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 81  SODIUM HYDROXIDE FEED SYSTEMS   LB/DAYLB/DAY 8.00E-01 8.34E+02 1.00E+00   1 01 1
      9.98E+02  3.91E+01 -8.63E-02  6.40E-05  1.78E+01  9.24E+00  3.11E-03  0.00E-00
      3.52E+01  3.03E-01 -1.47E-04  0.00E-00  1.66E+02  2.66E-01 -1.58E-04  0.00E-00
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.10 0.03 0.00 0.00 0.15 0.33 0.04 0.35
 82  POTASSIUM PERMANGANATE FEED SYS.LB/DAYLB/DAY 5.00E+00 2.50E+02 1.00E+00   1 01 1
      9.82E+02  3.68E+01 -1.41E-01  2.30E-04  1.46E+02  7.11E+00 -3.90E-02  7.51E-05
      1.74E+01  8.27E-01 -4.23E-03  7.99E-06  2.34E+02  1.03E+00 -1.08E-03  0.00E-00
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.44 0.00 0.00 0.10 0.09 0.07 0.30
 83  FERRIC CHLORIDE FEED SYSTEMS    LB/DAYLB/DAY 1.00E+00 7.50E+02 1.00E+00   1 01 1
      5.34E+02  5.51E+00 -2.01E-03  0.00E-00  5.10E+01  1.49E+00 -2.36E-03  1.78E-06
      1.81E+01  1.30E-01 -4.26E-06  0.00E-00  1.37E+02  3.35E-01 -1.61E-04  0.00E-00
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.49 0.00 0.00 0.13 0.25 0.13 0.00
 84  POWDERED ACT CARBON FEED, SLURRYLB/DAYLB/DAY 5.00E+01 2.50E+02 1.00E+00   1 01 1
      1.47E+03  1.79E+01  7.11E-03 -2.05E-05  8.91E+02  3.01E+01 -1.67E-01  4.75E-04
      3.95E+01  2.05E-01 -3.24E-04  8.76E-07  9.29E+01  1.26E+00 -3.73E-04  6.80E-07
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.80 0.00 0.00 0.09 0.05 0.06 0.00
 85  POWDERED ACT CARBON FEED, DRY   LB/DAYLB/DAY 5.00E+01 2.50E+02 1.00E+00   1 01 1
      1.44E+03  1.66E+01  5.05E-02 -1.18E-04  1.70E+03  6.93E+00 -2.05E-03  3.74E-06
      3.47E+01  2.84E-01  4.78E-05 -2.29E-07  1.17E+02  7.76E-01 -4.18E-04  9.65E-07
      0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 0.82 0.00 0.00 0.08 0.05 0.05 0.00
 86  SLUDGE DEWATERING LAGOONS       CU FT CF/YR  2.50E+03 1.47E+05 1.36E-01   1 00 1
      8.25E+02  2.03E-01 -7.91E-07  3.51E-12  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      5.93E+00  5.73E-02  8.13E-07 -2.89E-11  4.02E+00  4.00E-03 -4.58E-08  1.55E-12
     -1.78E-01  1.04E-02 -1.01E-07  2.25E-12  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.46 0.00 0.05 0.00 0.40 0.09 0.00 0.00
 87  CATION EXCHNG SOFTNG,1 DAY RFREQCU FT CU FT  3.00E+00 5.20E+02 1.00E+00   1 01 2
      9.91E+03  3.83E+02 -3.11E-01  0.00E-00 -5.42E-01  6.24E-02  3.41E-04  0.00E-00
      1.04E+02  8.13E+00 -4.54E-04 -1.77E-06  2.09E+02  5.64E-03  1.89E-05  0.00E-00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
      5.74E+03  1.38E+02 -1.75E-01  1.34E-04 0.08 0.39 0.03 0.03 0.07 0.03 0.07 0.30
 88  CATION EXCHNG SOFTNG,2 DAY RFREQCU FT CU FT  3.00E+00 5.20E+02 1.00E+00   1 01 2
      9.91E+03  3.83E+02 -3.11E-01  0.00E-00 -5.42E-01  6.24E-02  3.41E-04  0.00E-00
      3.99E+01  1.20E+01 -7.71E-02  1.95E-04  1.05E+02  8.94E-03 -2.51E-07  0.00E-00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
      5.74E+03  1.38E+02 -1.75E-01  1.34E-04 0.08 0.39 0.03 0.03 0.07 0.03 0.07 0.30
 89  CATION EXCHNG SOFTNG,4 DAY RFREQCU FT CU FT  3.00E+00 5.20E+02 1.00E+00   1 01 2
      9.91E+03  3.83E+02 -3.11E-01  0.00E-00 -5.42E-01  6.24E-02  3.41E-04  0.00E-00
      6.40E+01  5.34E+00 -3.50E-03  2.14E-06  5.55E+01 -1.10E-02 -2.53E-06  0.00E-00
      0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
      5.74E+03  1.38E+02 -1.75E-01  1.34E-04 0.08 0.39 0.03 0.03 0.07 0.03 0.07 0.30
 90  ANION EXCHNG NO3 REM,2/DAY RFREQCU FT CU FT  4.00E+00 5.20E+02 1.00E+00   1 01 2
      8.72E+03  8.72E+02 -2.53E+00  2.97E-03 -2.08E+01  5.50E+00 -1.46E-02  2.01E-05
      9.18E+01  6.47E+01 -3.35E-03  1.90E-06  3.88E+02  2.23E-02  1.92E-03 -2.34E-06
      0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
      5.68E+03  1.37E+02 -1.75E-01  1.37E-04 0.06 0.45 0.04 0.05 0.09 0.03 0.07 0.21
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TABLE 204. (Continued)

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 91  ANION EXCHNG NO3 REM,DAILY RFREQCU FT CU FT  4.00E+00 5.20E+02 1.00E+00   1 01 2
       8.72E+03  8.72E+02 -2.53E+00  2.97E-03 -7.51E+00  1.10E+00  1.48E-03  0.00E-00
       7.14E+01  5.26E+01 -2.13E-02  2.72E-05  1.97E+02  1.23E-01  1.50E-04  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       5.68E+03  1.37E+02 -1.75E-01  1.37E-04 0.06 0.45 0.04 0.05 0.09 0.03 0.07 0.21
 92  ANION EXCHNG NO3 REM,2 DAY RFREQCU FT CU FT  4.00E+00 5.20E+02 1.00E+00   1 01 2
       8.72E+03  8.72E+02 -2.53E+00  2.97E-03 -6.96E+00  1.06E+00 -4.41E-04  0.00E-00
       1.92E+02  3.89E+01  1.56E-02 -2.20E-05  9.90E+01  3.97E-02  1.13E-04  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       5.68E+03  1.37E+02 -1.75E-01  1.37E-04 0.06 0.45 0.04 0.05 0.09 0.03 0.07 0.21
 93  COUNTERCUR PACKED TOWER AER,10:1CU FT GPD    1.26E+01 4.53E+02 2.21E+03   1 00 1
       1.62E+04  1.01E+02 -2.21E-01  2.43E-04  1.39E+02  1.59E-01 -1.55E-07  1.10E-13
       1.69E+02  6.05E-04 -7.78E-10  5.54E-16  1.82E+02 -4.24E-07  1.87E-10  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.05 0.40 0.15 0.20 0.10 0.03 0.07 0.00
 94  COUNTERCUR PACKED TOWER AER,20:1CU FT GPD    1.26E+01 4.53E+02 2.21E+03   1 00 1
       1.56E+04  1.64E+02 -5.20E-01  7.05E-04 -7.89E+02  1.99E-01 -2.48E-07  1.83E-13
       1.69E+02  6.05E-04 -7.78E-10  5.54E-16  1.82E+02 -4.24E-07  1.87E-10  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.05 0.44 0.13 0.18 0.10 0.03 0.07 0.00
 95  SPRAY AERATION SYSTEMS           GPD   GPD    2.80E+04 1.01E+06 1.00E+00   1 00 1
       1.61E+04  5.93E-02  3.37E-08 -5.60E-14 -9.34E+01  8.66E-02 -2.88E-09  1.42E-15
       4.65E+01  4.03E-04  1.90E-10 -1.85E-16  4.32E+01  2.55E-04 -3.87E-10  2.08E-16
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.55 0.04 0.16 0.00 0.11 0.07 0.07 0.00
 96  CASCADE TRAY AERATORS            GPD   GPD    6.50E+04 1.00E+06 1.00E+00   1 00 1
       1.61E+04 -2.86E-02  1.25E-07 -7.87E-14 -1.21E+03  4.66E-02 -6.01E-08  4.05E-14
       1.20E+02  1.41E-04 -7.71E-11  9.67E-17  9.10E+01  1.16E-04 -1.28E-10  5.99E-17
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.07 0.35 0.21 0.00 0.24 0.04 0.09 0.00
 97  BRINE EVAP LAGOONS, NO LINER    SQ FT SQ FT  3.50E+03 6.53E+05 1.00E+00   1 00 1
       6.33E+03  5.20E-01 -2.81E-07  1.03E-13  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       1.01E+02  1.11E-03 -3.74E-11  9.39E-17  2.87E+01  2.51E-04 -1.25E-10  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.85 0.00 0.00 0.00 0.07 0.08 0.00 0.00
 98  BRINE EVAP LAGOONS, WITH LINER  SQ FT SQ FT  3.50E+03 6.53E+05 1.00E+00   1 00 1
       8.51E+03  1.01E+00 -8.03E-07  5.41E-13  0.00E+00  0.00E+00  0.00E+00  0.00E+00
       7.71E+01  1.53E-04 -8.90E-11  0.00E-00  2.17E+01  4.17E-05 -2.15E-11  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.51 0.40 0.00 0.00 0.04 0.05 0.00 0.00
 99  LIQUID SLUDGE HAUL,8 MPG,20 MPH GAL   ML/YR  1.60E+03 4.00E+03 2.50E+00   1 0012
       2.41E+03  3.58E+01 -1.37E-02  2.07E-06  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      -2.30E-14  1.05E-01 -1.42E-19  4.56E-24 -2.95E-01  6.29E-02 -9.45E-08  5.44E-12
       2.66E+00  1.23E-01  3.69E-07 -2.41E-11  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00
100  DEWATERED SLUDGE HAUL,8MPG,20MPHCU YD ML/YR  1.00E+02 1.00E+04 1.00E+00   1 0012
       2.51E+04 -7.33E-09  1.47E-11  1.46E-16  0.00E+00  0.00E+00  0.00E+00  0.00E+00
      -2.30E-14  1.05E-01 -1.42E-19  4.56E-24 -2.95E-01  6.29E-02 -9.45E-08  5.44E-12
       2.66E+00  1.23E-01  3.69E-07 -2.41E-11  0.00E-00  0.00E-00  0.00E-00  0.00E-00
       0.00E-00  0.00E-00  0.00E-00  0.00E-00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00
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REFERENCES

1. Process Plant Construction Estimating Standards, Volumes 1, 2, 3, & 4, Richardsons Engineering Services, Inc., Solana Beach, California.

2. Building Construction Cost Data, Robert Snow Means Company, Inc., Dexbury, Massachusetts.

3. Dodge Guide to Public Works and Heavy Construction Costs, Dodge Building Cost Services, McGraw-Hill, 1221 Avenue of the Americas, New York, New York.

4. Producer Prices and Price Indexes, Data for December, 1983. Bureau of Labor Statistics, U.S. Department of Labor.

5. Engineering News-Record, McGraw-Hill, Inc., 1221 Avenue of the Americas, New York, New York 10020, December 8, 1983.

6. Sorg, T.J. and G.S. Logsdon. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 2. JAWWA, 70, 379-393 (July 1979).

7. Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations, EPA-600/8-77-005, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978, 73 pp.

8. Bellack, E. Arsenic Removal from Potable Water. JAWWA, 63, 454-458, (July 1971).

9. Shen, Y.S. Study of Arsenic Removal from Drinking Water. JAWWA, 65, 543-548, (August 1973).

10. Sorg, T.J. and G.S. Logsdon. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 5, JAWWA, 72, 411-422, (July 1980).

11. Sorg, T.J., M. Csanady, and G.S. Logsdon. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 3. JAWWA, 70, 680-691, (December 1978).

12. Sorg, T.J. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 4, JAWWA, 71, 454-466, (August 1979).

13. Sorg, T.J. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics. JAWWA, 70, 105-12, (February 1978).

14. Rubel, F. and R.D. Woosley. Removal of Excess Fluoride from Drinking Water. EPA-570/9-78-001, U.S. Environmental Protection Agency, Washington, D.C. 16 pp.

15. Singh, G. and D.A. Clifford. The Equilibrium Fluoride Capacity of Activated Alumina. EPA-600/S2-81-082, U.S. Environmental Protection Agency, Cincinnati, Ohio.

16. Guter, G.A. Removal of Nitrate from Contaminated Water Supplies for Public Use. EPA-600/S2-81-029, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1981.

17. SCM Martin, Inc. Nitrate Removal for Small Public Water Systems. EPA-570/9-83-009, U.S. Environmental Protection Agency, Washington, D.C., June 1983.

18. Symons, J.M. Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon. U.S. Environmental Protection Agency, Cincinnati, Ohio, January 1978, 55 pp.

19. American Water Works Association, Inc. Water Quality and Treatment - A Handbook of Public Water Supplies. Third Edition, McGraw-Hill Book Company, New York, New York, 1971.

20. Symons, J.M., et. al. Treatment Techniques for Controlling Trihalomethanes in Drinking Water. EPA-600/2-81-156, U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1981, 289 pp.

21. American Water Works Association, Inc. Water Treatment Plant Design, AWWA, New York, New York, 1969. 353 pp.

22. Lineck, T.S., Gumerman, R.C., and Culp, R.L. Estimating Water Treatment Costs; Volume 4, Computer User's Manual for Retrieving and Updating Cost Data. EPA-600/2-79-162d, U.S. Environmental Protection Agency, Cincinnati, Ohio, August, 1979, 80 pp.

APPENDIX A

BUILDING CONSTRUCTION COSTS AND ENERGY REQUIREMENTS

CONSTRUCTION COST

Buildings used in small water treatment plants will vary in construction cost due to variations in construction requirements in different geographic locations, and also due to different degrees of architectural sophistication. In portions of the U.S. which experience severe winter weather, well constructed and well insulated buildings are required. In such climates, construction costs are typically higher than in locations which experience moderate winter weather.

Another important factor in determining construction cost is the architectural treatment provided. When buildings are in or near residential neighborhoods, aesthetically pleasing, although more expensive, buildings are often used. This is a general statement, and will vary with the attitude of the utility management toward compatibility with surrounding land use, as well as the budget available.

Figure A-1 presents a construction cost curve for buildings with 3.05 and 4.27 m (10 and 14 ft) ceiling heights. These are the two building heights which have been used in the development of construction costs presented in this report. The costs are for a building constructed on a 0.152 m (6 in) reinforced concrete slab, using block construction and a wood truss roof with asphalt shingles on plywood sheeting. Insulation was included for the roof only, and ventilation is provided by a propeller exhaust fan. Heating is electric, and a 3.05 m (10 ft) wide service door is provided. Buildings larger than 92.9 m^2 (1,000 sq ft) include washroom facilities.

In addition to the building cost, costs are included for a chainlink security fence with a gate, and a gravel parking area. Land costs and electrical service to the building are not included. As shown by Figure A-1, economies of scale are evident as the building square footage increases.

ENERGY REQUIREMENTS

Building energy requirements include lighting, ventilation, and heating. Lighting energy requirements are a function of the number of hours that the lights are utilized, ventilation energy requirements are a function of the volume of the building, and heating energy requirements are a function of the geographic location of the building. To calculate building energy requirements, the following assumptions were utilized:

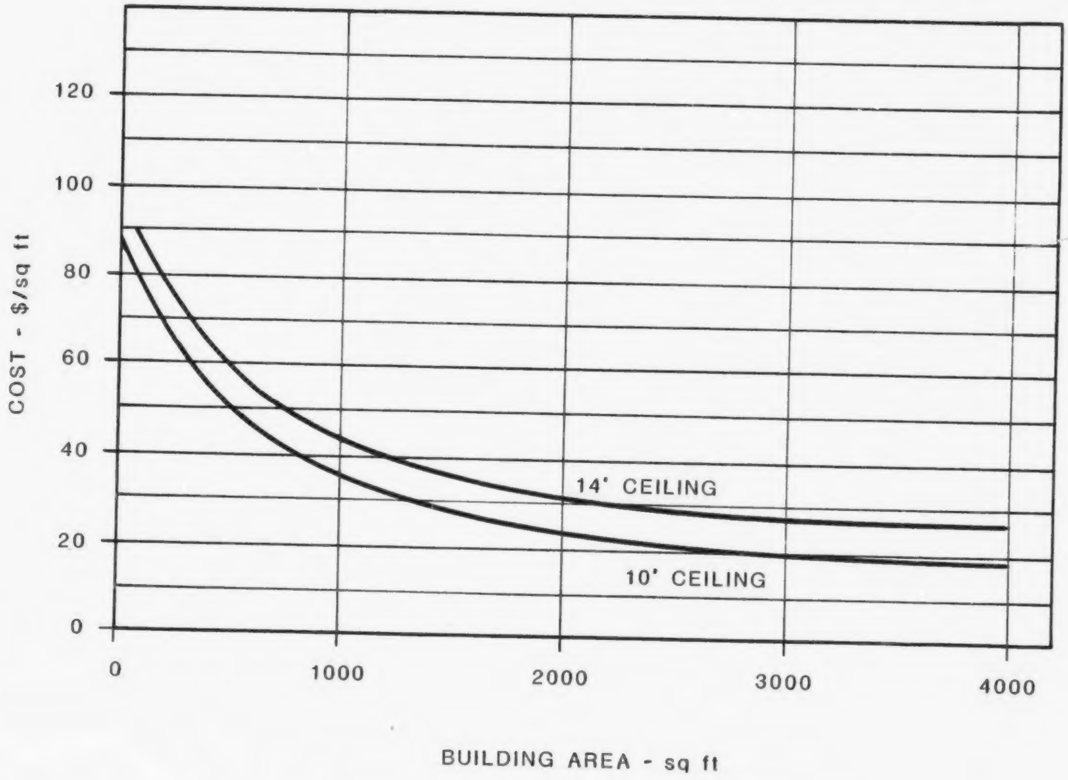


Figure A-1. Building construction costs.

- Lighting requirements are 21.5 watts/m^2 (2 watts/sq ft)
- Lights are on only when operators are present, which is three hours/day
- Air changes/hour are one during the heating season, and four during the nonheating season
- Walls and the roof are well insulated with U-values of 0.10 and 0.05 Btu/(hr) (sq ft) (°F) respectively
- Indoor design conditions for heating are 20°C (68°F) dry bulb
- Temperature data for each location is from "Facility Design and Planning Engineering Weather Data," Department of Air Force Manual AFM 88-29, Department of Army Technical Manual TM 5-785, Department of Navy Manual NAVFAC P-89, 1 July 1978

Calculated building energy values are shown in Tables A-1 and A-2 for 3.05 and 4.27 m (10 and 14 ft) high ceilings in buildings in 21 U.S. cities. Requirements average 156 kWh/m^2/y (14.5 kWh/sq ft/yr) for 3.05 m (10 ft) high ceilings and 209.8 kWh/m^2/y (19.5 kWh/sq ft/yr) for 4.27 m (15 ft) high ceilings. These values were used to calculate building energy in the cost data contained in this report.

TABLE A-1

BUILDING ENERGY REQUIREMENTS FOR 21 U.S. CITIES
(10-FOOT CEILING HEIGHT)

	Electrical Energy (kWh/sq ft/yr)			
City	Lighting	Ventilation	Heating	Total
Seattle, WA	2.2	0.4	13.9	16.5
Salt Lake City, UT	2.2	0.5	17.4	20.1
Omaha, NE	2.2	0.6	18.0	20.8
Minneapolis, MN	2.2	0.5	22.1	24.8
Chicago, IL	2.2	0.5	18.6	21.3
New York, NY	2.2	0.6	14.1	16.9
Boston, MA	2.2	0.5	17.8	20.5
San Francisco, CA	2.2	0.4	8.7	11.3
Denver, CO	2.2	0.5	18.4	21.1
St. Louis, MO	2.2	0.6	13.6	16.4
Las Vegas, NV	2.2	0.7	6.4	9.3
Richmond, VA	2.2	0.6	11.6	14.4
Nashville, TN	2.2	0.4	11.4	14.0
Washington, D.C.	2.2	0.6	14.0	16.8
Los Angeles, CA	2.2	0.5	5.3	8.0
Phoenix, AZ	2.2	0.8	4.9	7.9
Albuquerque, NM	2.2	0.6	12.5	15.3
Dallas, TX	2.2	0.7	7.2	10.1
Tampa, FL	2.2	0.9	2.1	5.2
Atlanta, GA	2.2	0.7	8.6	11.5
Miami, FL	2.2	1.0	0.6	3.8
Average	2.2	0.6	11.7	14.5

TABLE A-2

BUILDING ENERGY REQUIREMENTS FOR 21 U.S. CITIES (14-FOOT CEILING HEIGHT)

City	Electrical Energy (kWh/sq ft/yr)			
	Lighting	Ventilation	Heating	Total
Seattle, WA	2.2	0.6	19.3	22.1
Salt Lake City, UT	2.2	0.7	23.9	26.8
Omaha, NE	2.2	0.8	24.7	27.7
Minneapolis, MN	2.2	0.7	28.6	31.5
Chicago, IL	2.2	0.7	25.6	28.5
New York, NY	2.2	0.8	19.5	22.5
Boston, MA	2.2	0.7	26.8	29.7
San Francisco, CA	2.2	0.6	12.3	15.1
Denver, CO	2.2	0.7	25.3	28.2
St. Louis, MO	2.2	0.9	18.8	21.9
Las Vegas, NV	2.2	1.0	10.2	13.4
Richmond, VA	2.2	0.9	16.0	19.1
Nashville, TN	2.2	0.5	15.8	18.5
Washington, D.C.	2.2	0.8	19.4	22.4
Los Angeles, CA	2.2	0.7	7.8	10.7
Phoenix, AZ	2.2	1.1	6.9	10.2
Albuquerque, NM	2.2	0.8	17.2	20.2
Dallas, TX	2.2	1.0	10.0	13.2
Tampa, FL	2.2	1.2	3.0	6.4
Atlanta, GA	2.2	0.9	11.9	15.0
Miami, FL	2.2	1.4	0.9	4.5
Average	2.2	0.9	16.4	19.5

APPENDIX B

FIELD DATA COLLECTION

INTRODUCTON

Field data were collected for operating requirements, and where possible for construction cost, at 25 utilities. This data collection was performed by two subcontractors: ACT Systems, Inc. of Winter Park, Florida and Rubel and Hager, Inc. of Tucson, Arizona. ACT Systems was responsible for data collection at utilities in Eastern U.S., and Rubel and Hager was responsible for data collection at utilities in the Western U.S.

A separate report was prepared by the subcontractors for each utility visited. Due to the extensiveness of these reports, they are not included. However, a summary of each utility is presented in this Appendix. The order of arrangement of these summary reports is as follows:

1. Village of Western Springs, Illinois
2. Village of German Valley, Illinois
3. Village of Rouses Point, New York
4. Rockaway Township Water Department, New Jersey
5. Villa Rica Water Department, Villa Rica, Georgia
6. Borough of Rockaway, New Jersey
7. Village of Port Henry, New York
8. Village of Olympia Fields, Illinois
9. Fayette County Water System, Fayetteville, Georgia
10. Borough of Strasburg, Pennsylvania
11. Charlotte Harbor Water Association, Harbor Heights, Florida
12. Bryn Mawr Water Company, Vero Beach, Florida
13. Wurtsmith Air Force Base, Michigan
14. Town of Gila Bend, Arizona
15. Dell City, Texas
16. City of Bronson, Kansas
17. City of Richmond, Kansas
18. Jefferson County Rural Water District No. 11, Kansas
19. City of Rialto, California
20. City of Safford, Arizona
21. Davis Dam, Bullhead City, Arizona
22. City of Castle Dale, Utah, Castle Valley Special Service District
23. City of Ferron, Utah, Castle Valley Special Service District
24. Orangeville, Utah, Castle Valley Special Service District
25. McFarland, California, McFarland Mutual Water Company

VILLAGE OF WESTERN SPRINGS, ILLINOIS

The Village of Western Springs is located in Cook County, approximately 24.2 km (15 miles) west of Chicago, Illinois. The utility treats a groundwater supply using a package lime softening/coagulant addition process, recarbonation, filtration, and chlorination. The design capacity of the plant is 13,096 m^3/d (3.46 mgd) and the current average daily flow rate is 4,504 m^3/d (1.19 mgd). A process flow diagram showing points of chemical addition is shown in Figure B-1.

The treatment facilities are housed in a concrete block building with a basement; the building measures 24.4 x 18.3 m (80 x 60 ft). A package rectangular mixing/settling unit is used with 6 settling chambers surrounding a center slow-mixing chamber. Lime and soda ash are added for softening and alum is also added for clarification. Water flows from the settling chamber to a recarbonation basin, where carbon dioxide gas is added for reduction of pH. Water is next filtered through rapid sand filters, and then passes to a storage reservoir where chlorine is added. Sludges from the settling chambers and filter backwash are discharged into municipal sewer lines.

The building housing the treatment facilities was constructed in 1930; modifications to the filters were made in 1958 and the package mixing/settling unit was added in 1962. Design criteria for the principal treatment facilities are as follows:

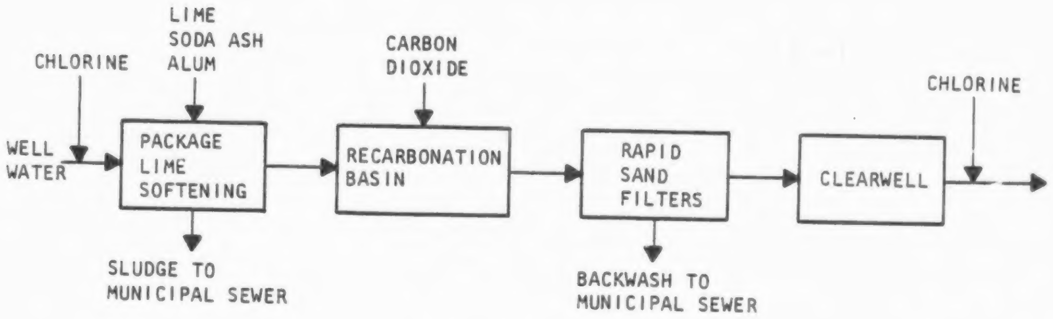
Package Mixing/Settling Unit	374.7 m^3 (99,000 gal) volume
Rapid Sand Filters	
Number	4
Capacity	37.86 L/s (600 gpm) each
Backwash	Required after 113.6 m^3 (30,000 gal) treated
Chlorination	908 kg (2,000 lb) cylinders
Storage Reservoir	1,892 m^3 (500,000 gal)

Operation and maintenance requirements and costs during 1981 were:

Process	Process Energy, kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Mixing/Settling	639,900	-	1,970	44,500
Recarbonation	-	-	1,970	12,500
Filtration	959,700	-	1,970	60,500
Chemical Feeding	10,100	1,630	420	4,800
Chemicals	-	-	-	44,300
Laboratory	-	80	1,580	10,100
General Plant	80,000	-	420	6,700
Total Plant O&M	1,689,700	1,710	8,330	183,400

The total operation and maintenance cost of $183,400 per year is equivalent to $0.112/$m^3$ ($423.99/million gallons) treated, based upon the following unit costs:

PLANT DESIGN CAPACITY = 13,096 m^3/d (3,460,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 4,504 m^3/d (1,190,000 GPD)



LIME
SODA ASH
ALUM
CHLORINE
CARBON
DIOXIDE
CHLORINE
WELL
WATER
PACKAGE
LIME
SOFTENING
RECARBONATION
BASIN
RAPID
SAND
FILTERS
CLEARWELL
SLUDGE TO
MUNICIPAL SEWER
BACKWASH TO
MUNICIPAL SEWER

Figure B-1. Village of Western Springs, Illinois.

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	194.51
Materials	-	-	3.94
Labor	6.35/hr	-	121.78
Lime	0.041/lb	236	67.00
Soda Ash	0.11/lb	13.0	9.91
Alum	0.1625/lb	11.8	13.28
Carbon Dioxide	0.12/lb	10.9	9.11
Chlorine	0.2675/lb	2.4	4.46
Total			423.99

VILLAGE OF GERMAN VALLEY, ILLINOIS

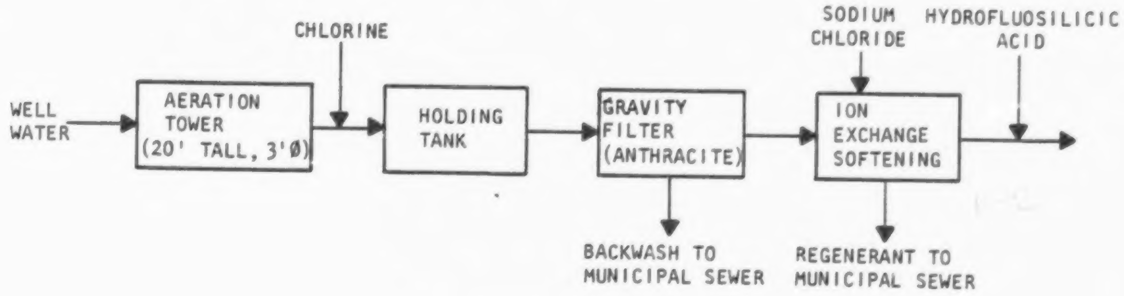
This utility operates a 378.5 m^3/d (0.1 mgd) capacity water treatment facility; in 1981 the average volume of treated water was 122.6 m^3/d (32,400 gpd). Groundwater is treated using countercurrent packed tower aeration, pressure filtration, and ion exchange softening. Treatment is provided to remove barium and iron, reduce hardness, add fluoride, and assure disinfection. A process flow diagram showing the points of chemical addition is shown on Figure B-2.

The treatment facilities are housed in a 6.1 x 6.1 m (20 x 20 ft) single-story concrete block structure. Raw water under pressure is discharged into an aeration tower that is erected atop the treatment building. Oxidation of the raw water aids in odor and iron removal. After cascading through the aeration tower, the water enters a 2.89 m^3 (763 gal) holding tank at the base of the aeration tower. Chlorine is introduced for disinfection into the holding tank. Providing approximately eight minutes detention time, the holding tank then feeds the pressure filter, which contains four cells with graduated anthracite media. Normally, the filter is backwashed using finished water once a week. Effluent from the filter is pumped to dual zeolite softening units. Following softening, hydrofluosilicic acid is added prior to storage in an elevated tank. The softening units automatically regenerate alternately every 94.6 m^3 (25,000 gal) using a salt solution. Under normal flow production conditions, each softener is regenerated once every two days. Filter backwash water and regenerant brine are discharged to the Village's municipal sewer system.

The treatment facilities were constructed in 1972. No data on the treatment plant construction costs could be obtained during the site visit. Design criteria for the principal treatment facilities are as follows:

Aeration Tower	6.1 m (20 ft) tall
Holding Tank	0.91 m (3 ft) diameter 2.89 m^3 (763 gal)
Anthracite Filter	1 - four cells, total surface area is 3.1 m^2 (33.4 sq ft)
Zeolite Softeners	2 @ 2.46 L/s (39 gpm) each 94.6 m^3 (25,000 gpd) capacity each

DESIGN CAPACITY = 378.5 m^3 (100,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 122.6 m^3 (32,400 GPD)



WELL WATER
AERATION TOWER (20' TALL, 3'Ø)
CHLORINE
HOLDING TANK
GRAVITY FILTER (ANTHRACITE)
BACKWASH TO MUNICIPAL SEWER
SODIUM CHLORIDE
ION EXCHANGE SOFTENING
REGENERANT TO MUNICIPAL SEWER
HYDROFLUOSILICIC ACID

Figure B-2. Village of German Valley, Illinois.

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Aeration and Filtration	5,300	50	94	500
Zeolite Softening	2,600	50	94	370
Chemical Feeding	900	-	125	290
Chemicals	-	-	-	3,650
Laboratory	-	30	520	1,050
General Plant Requirements	0	0	208	410
Total Plant O&M	8,800	130	1,041	6,270

The total operation and maintenance cost is equivalent to $0.14/m^3 ($529.40/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	36.70
Materials	-	-	11.00
Labor	1.97/hr	-	173.10
Chlorine	0.3075/lb	4.1	10.60
Salt	0.06/lb	592.0	296.20
Hydrofluosilicic Acid	0.1225/lb	1.8	1.80
Total			529.40

VILLAGE OF ROUSES POINT, NEW YORK

This utility operates an 8,516 m^3/d (2.25 mgd) capacity water treatment facility; in 1981 the average volume of treated water was 4,424 m^3/d (1.1688 mgd). Surface water from Lake Champlain is treated by using pressure diatomaceous earth filtration and chlorination. Treatment is provided to remove suspended solids and assure disinfection. A process flow diagram showing the point of chlorine addition is shown on Figure B-3.

The treatment facilities are housed in a 190.5 m^2 (2,050 sq ft) single-story concrete block building. The treatment plant consists of two parallel treatment systems, both of which employ diatomaceous earth filters. Raw water flows by gravity to two separate wet wells, each serving one of the two treatment systems. The intake pumps pump the raw water to the two separate filter systems. Two types of pressure diatomaceous earth filters are used: one system uses cloth liners with diatomaceous earth, and the other uses porous stone tubes with diatomaceous earth. Chlorine is fed prior to filtration. On the average, backwashing of either type of filter is accomplished every four days. Sludge produced during backwashing is discharged to the municipal sewer system.

PLANT DESIGN CAPACITY = 8,516 m^3/d (2,250,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1981 = 4,424 m^3/d (1,168,800 GPD)

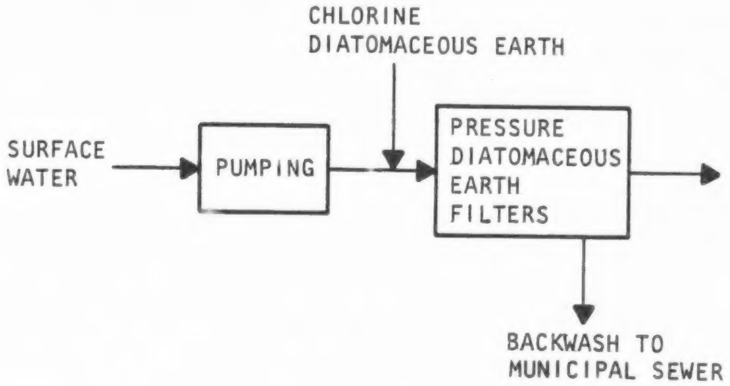

CHLORINE
DIATOMACEOUS EARTH
SURFACE WATER
PUMPING
PRESSURE DIATOMACEOUS EARTH FILTERS
BACKWASH TO MUNICIPAL SEWER

Figure B-3. Village of Rouses Point, New York.

The older treatment system, which utilizes the cloth-type filters, was constructed in 1963. The newer treatment system, which utilizes the porous stone-type filters, was constructed in 1975. No data were available on the construction costs of the facilities. Design criteria for the principal facilities are as follows:

Pressure Diatomaceous Earth Filters	
Older Units	2 - 16.4 L/s (260 gpm) each, 1.52 m (60 in.) diameter, 1.37 m (54 in.) long, horizontal units
Newer Units	4 - 16.4 L/s (260 gpm) each, 1.52 m (60 in.) diameter, 2.43 m (96 in.) tall, vertical units

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Diatomaceous Earth Filters	693,200	2,720	5,052	54,980
Diatomaceous Earth Feeding	7,400	70	124	1,100
Chlorine Feeding	7,400	70	124	1,100
Chemicals	-	-	-	11,610
General	-	500	936	6,720
Total Plant O&M	708,000	3,360	6,236	75,510

The total cost is equivalent to $\$0.0467/m^3$ ($176.96/million gallons) treated based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.027/kWh	-	44.80
Materials	-	-	7.89
Labor	6.64/hr	-	97.06
Diatomaceous Earth	0.1362/lb	20.9	23.70
Chlorine	0.1967/lb	2.1	3.51
Total			176.96

ROCKAWAY TOWNSHIP WATER DEPARTMENT, NEW JERSEY

This utility operates a 4,164 m^3/d (1.1 mgd) capacity water treatment facility; in 1981 the average volume of treated water was 3,590 m^3/d (948,550 gpd). Groundwater is treated using air stripping, pressure granular activated carbon filters and chlorination. Treatment is provided to remove trichloroethylene and di-isopropyl ether and to assure disinfection. A process flow diagram showing the point of chlorine addition is shown on Figure B-4.

PLANT DESIGN CAPACITY = 4,164 m^3/d (1,100,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 3,590 m^3/d (948,550 GPD)

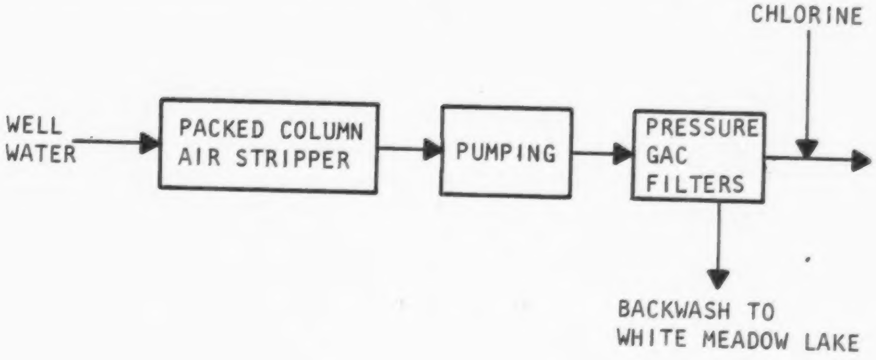

CHLORINE
WELL WATER
PACKED COLUMN AIR STRIPPER
PUMPING
PRESSURE GAC FILTERS
BACKWASH TO WHITE MEADOW LAKE

Figure B-4. **Rockaway Township Water Department, New Jersey.**

The activated carbon towers are housed in a 7.62 x 15.24 m (25 x 50 ft) aluminum building. External to this building is the air stripping facility. Raw water from three wells is pumped to a 1.22 m (4 ft) diameter air stripping column which is randomly packed with 7.62 m (25 ft) of plastic media and equipped with forced-air blowers. The action of the water splashing over the plastic media combined with a countercurrent of forced air helps to volatilize and remove organics from the raw water. Directly beneath the column is a 18.93 m^3 (5,000 gal) sump which supplies booster pumps feeding two carbon filters. The granular activated carbon filters remove remaining organics from the water. Filter effluent is chlorinated prior to distribution. Normally, breakthrough in the carbon filter occurs after four weeks of operation, necessitating frequent changes of the carbon. When the carbon is changed, the newly installed filter media is backwashed, and the spent backwash water is discharged to White Meadow Lake.

After the discovery of trichloroethylene and di-isopropyl ether in the raw water supply in 1979-1980, the air stripping column and activated carbon were installed. Data are unavailable on construction costs of these facilities as a whole. Design criteria for the principal treatment facilities are as follows:

Packed Column Air Stripper	1 unit -	1.22 m (4 ft) diameter, 7.62 m (25 ft) tall, randomly packed plastic media, forced-air blowers
Granular Activated Carbon Filters	2 units -	9,080 kg (20,000 lbs) media each, 26.5 L/s (420 gpm) each

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Air Stripper	474,700	200	2,341	37,070
Carbon Filters	37,800	-	780	6,270
Chemical Feeding	13,400	50	2	730
Chemicals	-	-	-	187,610
Laboratory	-	440	1,249	7,450
General	-	1,300	1,871	11,800
Total Plant O&M	525,900	1,990	6,243	250,930

The total cost is equivalent to \$0.19 m^3 (\$724.74/million gallons) treated based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.05/kWh	-	75.94
Materials	-	-	5.75
Labor	5.62/hr	-	101.16
Chlorine	0.23/lb	0.6	1.20
Carbon	0.78/lb	693.2 lb/mg Treated	540.69
Total			724.74

VILLA RICA WATER DEPARTMENT, VILLA RICA, GEORGIA

This utility operates a 3,785 m^3/d (1.0 mgd) capacity water treatment facility; in 1981 the average volume of treated water was 1,488 m^3/d (393,000 gpd). Surface water from an impoundment on the Little Tallapoosa River is treated by using lime softening, chlorine dioxide addition, flocculation, sedimentation, and filtration. Treatment is provided to remove manganese and iron and add fluoride. A process flow diagram showing the points of chemical addition is shown on Figure B-5.

The treatment facilities are housed in a 9.14 x 18.3 m (30 x 60 ft) concrete block structure three stories tall located on a hillside to allow gravity flow through the plant. Raw water first enters the flash mix chamber into which lime and alum are directly fed. Sodium chlorite is mixed into a solution and combined with chlorine by the hypochlorinator to generate chlorine dioxide which is then introduced into the flash mix chamber. Chlorine dioxide aids in removal of manganese and iron. The mixed flow enters two open flocculation basins followed by two open sedimentation basins. Next, water flows by gravity to two gravity rapid sand filters. Normally, filter run times average 31 hours between backwashings. All sludge from the sedimentation basins and filter backwash water is discharged by gravity to Little Tallapoosa River. Following filtration, water enters a clearwell where lime (for pH adjustment), sodium silicofluoride, and hexametaphosphate are added.

Construction of the treatment facilities was completed in 1966. Data are unavailable on the construction cost of the facilities. Design criteria for the principal treatment facilities are as follows:

Flocculation and Sedimentation Basins	9.14 x 18.3 m (30 x 60 ft)
Rapid Sand Filters	2 units, sand and gravel media
Clearwell Storage	302.8 m^3 (80,000 gallons)

Operation and maintenance requirements and costs based upon year 1981 conditions were:

PLANT DESIGN CAPACITY = 3,785 m^3/d (1,000,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1981 = 1,491 m^3/d (393,900 GPD)

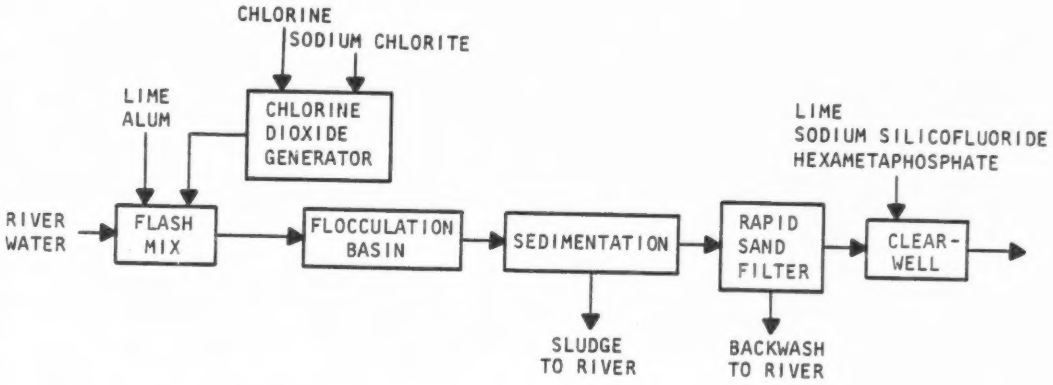

CHLORINE
SODIUM CHLORITE
LIME
ALUM
CHLORINE DIOXIDE GENERATOR
LIME
SODIUM SILICOFLUORIDE
HEXAMETAPHOSPHATE
RIVER WATER
FLASH MIX
FLOCCULATION BASIN
SEDIMENTATION
RAPID SAND FILTER
CLEAR-WELL
SLUDGE TO RIVER
BACKWASH TO RIVER

Figure B-5. **Villa Rica Water Department, Villa Rica, Georgia.**

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Flash Mix	19,800	500	455	3,990
Flocculation/ Sedimentation	6,300	2,500	573	5,960
Rapid Sand Filtration	188,100	2,500	1,138	18,150
Clearwell	-	300	136	1,050
Chemical Feeding	23,800	1,000	425	4,530
Chemicals	-	-	-	20,060
Laboratory	-	2,100	2,477	15,660
General Plant Requirements	67,300	2,100	620	8,850
Total Plant O&M	305,300	11,000	5,824	78,250

The total cost is equivalent to \$0.144 m^3 (\$544.21/million gallons) treated based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	106.12
Materials	-	-	76.15
Labor	5.49/hr	-	222.40
Lime	0.089/lb	15.7	11.68
Alum	0.161/lb	44.4	59.68
Chlorine	0.22/lb	6.4	11.65
Hexametaphosphate	0.62/lb	1.0	5.11
Sodium Silicofluoride	0.2555/lb	2.4	5.10
Sodium Chlorite	1.345/lb	2.8	32.01
Post-Lime	0.089/lb	19.3	14.31
Total			$544.21

Although not shown separately in the above figures, the chlorine dioxide generation requirements were: process energy = 3,960 kWh/yr; maintenance material = \$300/yr; and labor = 120 hr/yr.

BOROUGH OF ROCKAWAY, NEW JERSEY

This utility operates a 9,084 m^3/d (2.4 mgd) capacity water treatment facility; in 1981 the average volume of treated water was 3,751 m^3/d (990,900 gpd). Groundwater is treated using pressure granular activated carbon filters and chlorination. Treatment is provided to remove trichloroethylene and other organics and to assure disinfection. A process flow diagram showing the point of chlorine addition is shown on Figure B-6.

The treatment facilities are housed in a 7.62 x 17.68 m (25 x 58 ft) single-story concrete block building. Raw water from wells is pumped to three granulated activated carbon filters, each containing 9,080 kg (20,000 lb) of activated carbon. Filter effluent is chlorinated and flows into three 45.4 m^3

PLANT DESIGN CAPACITY = 9,084 m^3/d (2,400,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1981 = 3,751 m^3/d (990,900 GPD)

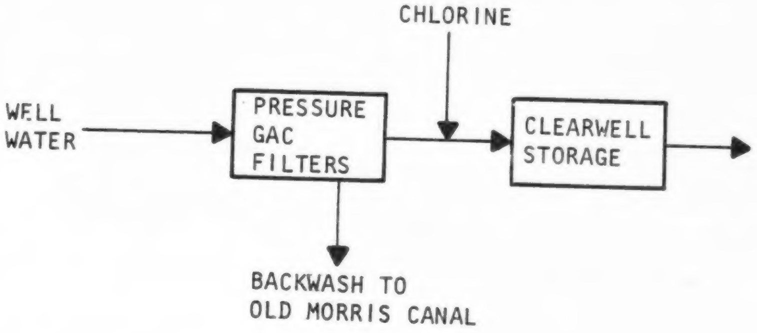

CHLORINE
WELL WATER
PRESSURE GAC FILTERS
CLEARWELL STORAGE
BACKWASH TO OLD MORRIS CANAL

Figure B-6. **Borough of Rockaway, New Jersey.**

(12,000 gal) clearwells which supply the distribution system. Normally, the activated carbon is replaced by an outside contractor when the level of effluent trichloroethylene exceeds 25 ppb. The new filter media is backwashed and returned to service. Spent backwash water is discharged to Old Morris Canal.

Construction of the treatment facilities was completed in 1981. No data on construction costs of the facilities were obtained during the site visit. Design criteria for the principal treatment facilities are as follows:

Granular Activated Carbon Filters	3 units - 9,080 kg (20,000 lb) media each, 4,164-9,084 m^3/d (1.1 - 2.4 mgd) each
Clearwells	3 fiberglass tanks, 9,080 kg (12,000 gal) each

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Carbon Filter	149,650	980	271	10,630
Chlorine Feeding	2,210	0	9	180
Chlorine	-	-	-	220
Carbon	-	-	-	47,940
Laboratory	-	-	0	0
General	-	330	802	6,750
Total Plant O&M	151,860	1,310	1,082	65,720

The total cost is equivalent to \$0.048/m^3 (\$181.71/million gallons) treated based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	20.99
Materials	-	-	3.60
Labor	8.01/hr	-	23.96
Chlorine	0.23/lb	0.3 mg/L	0.61
Carbon	0.799/lb	165.9 lb/mg Treated	132.56
Total			181.71

VILLAGE OF PORT HENRY, NEW YORK

The water department for the Village of Port Henry operates a 378.5 m^3/d (100,000 gpd) capacity water treatment facility; in 1981 the average volume of treated water was 311.3 m^3/d (82,250 gpd). Surface water from an impoundment on the Pelfisker Creek is treated by using filtration and chlorination. Treatment is provided to remove suspended solids and assure disinfection. A process flow diagram showing the point of chlorine addition is shown on Figure B-7.

PLANT DESIGN CAPACITY = 378.5 m^3/d (100,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1981 = 311.3 m^3/d (82,250 GPD)

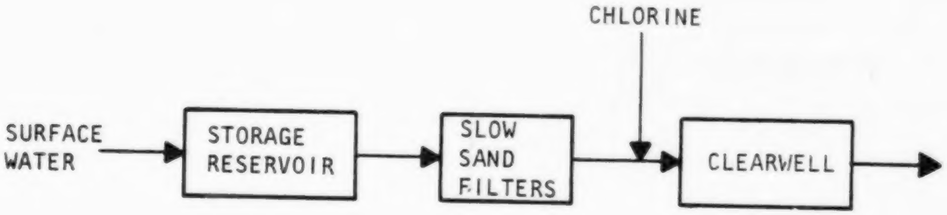

CHLORINE
SURFACE WATER
STORAGE RESERVOIR
SLOW SAND FILTERS
CLEARWELL

Figure B-7. Village of Port Henry, New York.

The treatment facilities consist of two open reservoirs and a two-story concrete block building which houses the treatment equipment. Raw water flows by gravity from the impoundment to a 3,785 m^3 (1.0 million gallon) concrete storage reservoir situated on a hill above the plant. From this upper reservoir water flows to a holding basin that controls the gravity flow to three parallel slow sand filters. In the clearwell beneath the filters, water is chlorinated by means of a gas chlorinator. Finished water then flows to the lower reservoir which is uncovered and located adjacent to the treatment plant. From this 2,555 m^3 (675,000 gallon) capacity reservoir, finished water flows into the distribution system. Sludge from sand filters washing process is discharged to Mill Pond Creek.

The original treatment plant was installed in 1892 with new equipment being added as it became needed since that time. Data are unavailable on the cost of construction of the facilities. Design criteria for the principal facilities are as follows:

Upper Reservoir	30.5 x 30.5 x 4.6 m (100 x 100 x 15 ft) deep, 3,785 m^3 (1.0 million gallons)
Holding Basin	1.22 x 3.96 x 3.66 m (4 x 13 x 12 ft) deep
Slow Sand Filters	3 - 6.71 x 15.24 (22 x 50 ft) each, media -- 0.91 m (3 ft) soil, 0.76 m (2.5 ft) sand, 3.05 m (10 ft) gravel
Lower Reservoir	15.24 x 15.24 x 3.66 m (50 x 50 x 12 ft) deep, 2,555 m^3 (675,000 gal)

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Slow Sand Filters	0	50	1,912	5,940
Chemical Feeding	420	0	37	134
Chemicals	-	-	-	359
Laboratory	-	20	130	420
General Plant Requirements	2,980	30	520	1,781
Total Plant O&M	3,400	100	2,599	8,630

The total cost is equivalent to \$0.076/m^3 (\$287.47/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	5.66
Materials	-	-	3.20
Labor	3.08/hr	-	266.65
Chlorine	0.2076/lb	6.9	11.96
Total			287.47

VILLAGE OF OLYMPIA FIELDS, ILLINOIS

This utility operates a treatment plant with a design capacity of 2,725 m^3/d (0.72 mgd), and a current average flow rate of 1,926 m^3/d (0.5088 mgd). The plant treats a groundwater supply using lime softening, recarbonation, and pressure diatomaceous earth filtration. Raw water quality meets requirements of the Interim Primary Drinking Water Regulations, and treatment is provided only to reduce hardness, add fluoride, and assure disinfection. A process flow diagram showing points of chemical addition is shown in Figure B-8.

The treatment facilities are housed in the base of a 21.94 m (72 ft) diameter, prestressed concrete water tower. The first treatment process is the lime softening unit, which is the point of addition of not only lime, but also alum, soda ash, and polyphosphate. The purpose of the latter is to stabilize the water and prevent calcium deposition. In the recarbonation basin, carbon dioxide gas (purchased as a liquid) is added, as is fluosilicic acid and gaseous chlorine (purchased in 68.1 kg (150 lb) cylinders). Next, a 56.78 m^3 (15,000 gal) holding basin is used as a sump for booster pumps, which pump water to the diatomaceous earth (DE) filters. Normally, each of these DE filters is backwashed every eight hours. Sludge produced during lime softening and backwash of the DE filters is discharged to the municipal sewer system.

The treatment facilities were constructed in 1958 as part of an overall project which also included wells, pumping facilities, and the water storage tower. No data could be obtained during the site visit on the portion of the total project cost which was for treatment plant construction. Design criteria for the principal treatment facilities are as follows:

Lime Softener	31.55 L/s (500 gpm)
Recarbonation Basin	56.78 m^3 (15,000 gal)
Holding Basin	56.78 m^3 (15,000 gal)
DE Filters	2 @ 15.78 L/s (250 gpm) each, diameter is 1.52 m (5 ft) and total surface area is 3.64 m^2 (39.2 sq ft)

Operation and maintenance requirements and costs based upon year 1981 conditions were:

PLANT DESIGN CAPACITY = 2,725 m^3/d (720,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 1,926 m^3/d (508,800 GPD)

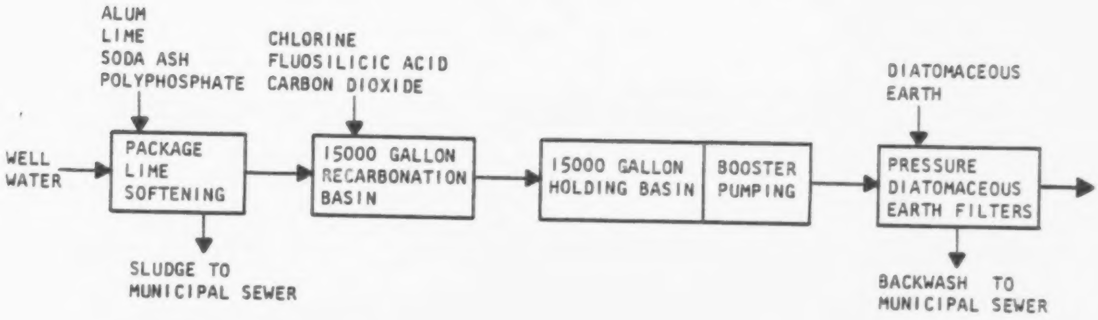

ALUM
LIME
SODA ASH
POLYPHOSPHATE
CHLORINE
FLUOSILICIC ACID
CARBON DIOXIDE
DIATOMACEOUS EARTH
WELL WATER
PACKAGE LIME SOFTENING
15000 GALLON RECARBONATION BASIN
15000 GALLON HOLDING BASIN
BOOSTER PUMPING
PRESSURE DIATOMACEOUS EARTH FILTERS
SLUDGE TO MUNICIPAL SEWER
BACKWASH TO MUNICIPAL SEWER

Figure B-8. Village of Olympia Fields, Illinois.

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Lime Softener	28,200	0	3,120	14,000
Recarbonation Basin	0	0	520	2,600
Holding Basin	0	0	520	2,600
Diatomaceous Earth Filter	97,700	700	3,120	18,600
Chemical Feeding	17,500	680	1,560	7,800
Laboratory	-	680	1,040	4,900
General Plant Requirements	156,000	680	520	10,600
Chemicals	-	-	-	97,000
Total Plant O&M	299,400	2,740	10,400	158,100

The total cost is equivalent to $0.22/m^3$ ($842.00/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	80.50
Materials	-	-	14.60
Labor	4.02/hr	-	224.80
Chlorine	0.25/lb	5.3	11.10
Fluosilicic Acid	0.12/lb	3.5	3.50
Lime	0.045/lb	546.0	204.80
Soda Ash	0.089/lb	211.0	156.50
Sodium Aluminate	0.269/lb	19.9	44.70
Diatomaceous Earth	0.207/lb	11.0	19.10
Polyphosphate	1.349/lb	2.5	28.00
Carbon Dioxide	0.123/lb	53.0	54.40
Total			842.00

FAYETTE COUNTY WATER SYSTEM, FAYETTEVILLE, GEORGIA

This utility operates a treatment plant with a design capacity of 1,893 m^3/d (0.50 mgd), and a current average flow rate of 1,803 m^3/d (0.4764 mgd). The plant treats surface water using flocculation, sedimentation, and rapid sand filtration. Chlorine dioxide is used as a pre-disinfectant, and chlorine is used as a post-disinfectant. A process flow diagram is shown in Figure B-9.

The majority of the treatment facilities are housed in a two-story concrete block building. Rapid mix, flocculation, and sedimentation are located outside; sand filters, chemical storage and chemical feed are located on the upper level, and high-service pumping and the clearwell are located on the lower level. During flocculation, energy input is provided by wooden baffles which provide sufficient turbulence during water passage. Powdered activated carbon is added seasonally, for taste and odor control.

PLANT DESIGN CAPACITY = 1,893 m^3/d (500,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 1,803 m^3/d (476,400 GPD)

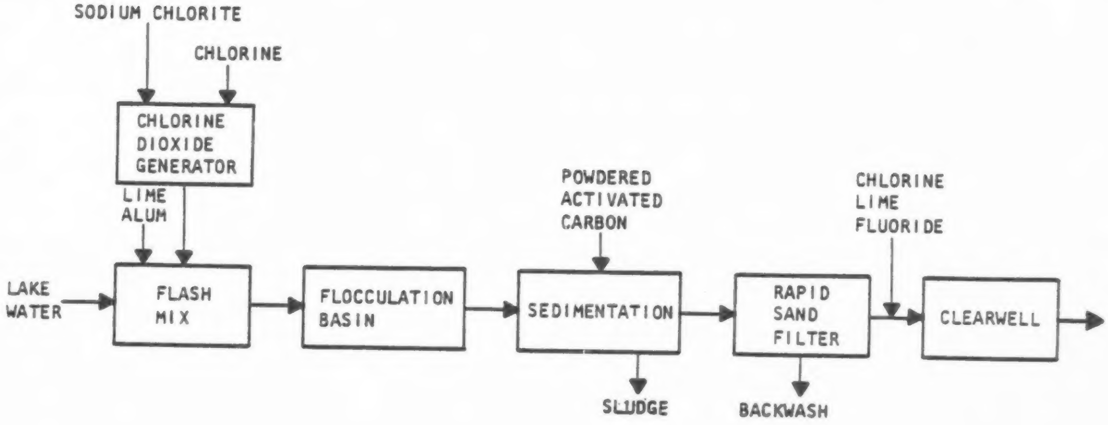

SODIUM CHLORITE
CHLORINE
CHLORINE DIOXIDE GENERATOR
LIME
ALUM
LAKE WATER
FLASH MIX
FLOCCULATION BASIN
POWDERED ACTIVATED CARBON
SEDIMENTATION
SLUDGE
RAPID SAND FILTER
BACKWASH
CHLORINE
LIME
FLUORIDE
CLEARWELL

Figure B-9. Fayette County Water System, Fayetteville,Georgia.

Chlorine dioxide is generated by mixing liquid sodium chlorite with liquid sodium hypochlorite. The sodium chlorite solution is produced using dry sodium chlorite and a volumetric feeder. Gaseous chlorine is used for final chlorination.

Neither the year of plant construction nor the plant construction cost were ascertained during the site visit.

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Flash Mix	0	1,770	60	2,200
Flocculation/ Sedimentation	5,400	1,770	1,040	9,100
Rapid Sand Filtration	63,600	1,770	1,390	14,400
Chemical Feeding	40,000	0	350	4,400
Chemicals	-	-	-	38,000
Laboratory	0	940	2,320	16,700
General Plant Requirements	151,200	-	2,130	22,000
Total Plant O&M	260,200	6,250	7,290	106,800

The costs are based upon an electrical rate of $0.05/kWh and a labor rate (including fringes) of $6.80/hr.

The total O&M cost is equivalent to $0.163/m^3 ($615.21/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	74.80
Maintenance Material	-	-	35.94
Labor	6.80/hr	-	285.03
Lime (Pre & Post)	0.70/lb	27.5	161.14
Alum	0.15/lb	28.9	27.85
Pre-Chlorine	0.25/lb	3.9	8.20
Sodium Chlorite	1.28/lb	1.4	15.28
Fluoride	0.23/lb	1.1	2.11
Post-Chloride	0.25/lb	2.3	4.86
Total			615.21

Although not specifically shown above, the costs attributed to chlorine dioxide generation were 11,200 kWh/yr for power and 101 hr/yr for labor. There was no allocated cost for maintenance material.

BOROUGH OF STRASBURG, PENNSYLVANIA

This utility operates a 1,295 m^3/d (342,000 gpd) capacity water treatment facility; in 1981 the average volume of treated water was 502.6 m^3/d (132,800 gpd). Groundwater is treated using ozonation to assure disinfection. A process flow diagram showing the points of chemical addition is shown on Figure B-10.

The treatment facilities are in a single-story concrete block structure with a basement measuring 4.27 x 4.27 m (14 x 14 ft). The basement contains liquid hypochlorite chlorination equipment which is used only as an emergency backup should the ozonation system fail. Under normal conditions, raw water supplied by fifteen springs and one well flows to the underground ozone contact chamber which is near the building. Ozone gas, produced by the ozone generator, is forced into the 9.75 m (32 ft) deep concrete contact chamber and mixed using a diffuser. Soda ash is added to maintain a neutral pH which is most favorable for ozone disinfection. From the contact chamber, water flows by gravity to the distribution system.

The ozonation equipment was installed in 1972. Construction cost data could not be obtained during the site visit. Design criteria for the principal treatment facilities are as follows:

Ozonator	1 - 1.82 kg (4 lb/day) capacity
Ozone Contact Chamber	1 - 9.75 m (32 ft) deep, 2 to 5 minutes detention time

Operation and maintenance requirements and costs based upon year 1981 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Ozone Contact	20,100	3,850	70	5,620
Soda Ash Feeding	1,800	-	260	2,190
Soda Ash	-	-	-	620
Laboratory	-	-	130	1,040
General	2,500	-	60	630
Total Plant O&M	24,400	3,850	520	10,100

The total cost is equivalent to $0.055/$m^3$ ($208.30/million gallons) treated based upon the following units costs:

PLANT DESIGN CAPACITY = 1,295 m^3/d (342,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 502.6 m^3/d (132,800 GPD)

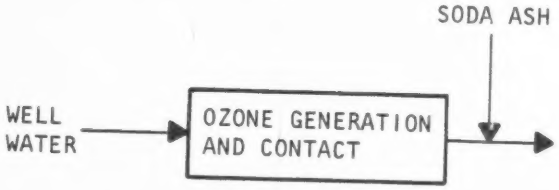

SODA ASH
WELL WATER
OZONE GENERATION AND CONTACT

Figure B-10. **Borough of Strasburg, Pennsylvania.**

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.06/kWh	-	30.20
Materials	-	-	79.40
Labor	8.00/hr	-	85.80
Soda Ash	0.12/lb	12.9	12.90
Total			208.30

CHARLOTTE HARBOR WATER ASSOCIATION, HARBOR HEIGHTS, FLORIDA

The Charlotte Harbor Water Association is located in Charlotte County, Florida, along the Gulf Coast. This utility treats a groundwater supply using chemical pretreatment, prefiltration, reverse osmosis (R/O), chemical post-treatment, and degasification prior to storage near the treatment plant. The average plant design capacity is 1,703 m^3/d (450,000 gpd), and the plant currently treats an average daily flow of 1,071 m^3/d (283,000 gpd). A process flow diagram showing points of chemical addition is shown in Figure B-11.

The treatment facilities are housed in a single-story concrete block building, along with a garage, administrative office space, and a laboratory room. The entire building measures 18.3 x 18.3 m (60 x 60 ft), while the treatment facilities are contained in an area of 9.14 x 12.2 m (30 x 40 ft). Chemical pretreatment of the raw water includes introduction of sulfuric acid which reduces pH of the feed water to approximately 5.4, and the addition of sodium hexametaphosphate which inhibits the precipitation of calcium sulfate.

Following chemical pretreatment, the water is passed through cartridge polypropylene prefilters. The filters are equipped with pressure gauges which indicate increases in headloss, alerting the operator that replacement or washing is required.

Following filtration, the feed water is pumped by pressurization pumps to three separate reverse osmosis units. The first two units, which became operational in July, 1978, and were modified in April, 1979, are capable of producing 1,136 m^3/d (300,000 gpd) of permeate. In November 1980, a third reverse osmosis unit was added, capable of producing 567.8 m^3/d (150,000 gpd) of permeate. The third R/O unit operates at a lower pressure than the first two units. The total production capability of the three R/O units is 1,703 m^3/d (450,000 gpd). The reject brine from the three R/O units is discharged into a drainage canal. A portion (23%) of untreated water is blended with the treated permeate to produce water of satisfactory quality.

Permeate is stabilized with the addition of soda ash prior to entering degasification. Degasification primarily removes dissolved carbon dioxide which is produced by pretreatment acid addition. Immediately following degasification, water is transferred to a storage reservoir where chlorine is added. Design criteria for the principal treatment facilities are as follows:

PLANT DESIGN CAPACITY = 1,703 m^3/d (450,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 1,071 m^3/d (283,000 GPD)

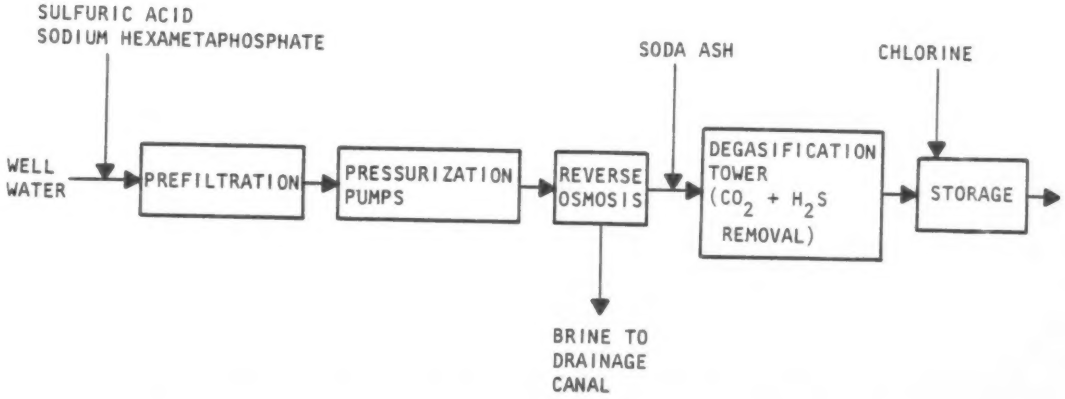

SULFURIC ACID
SODIUM HEXAMETAPHOSPHATE
SODA ASH
CHLORINE
WELL WATER
PREFILTRATION
PRESSURIZATION PUMPS
REVERSE OSMOSIS
DEGASIFICATION TOWER (CO_2 + H_2S REMOVAL)
STORAGE
BRINE TO DRAINAGE CANAL

Figure B-11. Charlotte Harbor Water Association, Harbor Heights, Florida.

Reverse Osmosis Pressurization Pumps	2 @ 44.7 kw (60 hp) each, 27.4 kg/cm^2 (390 psi) operating pressure 1 @ 55.9 kw (75 hp), 16.5 kg/cm^2 (235 psi) operating pressure
Membrane Type	Units 1 and 2 - Spiral-wound cellulose acetate Unit 3 - Hollow fiber
Storage Reservoir	340.6 m^3 (90,000 gal)

Operating and maintenance requirements and costs during 1981 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Cartridge Prefilters	-	500	1,500	7,200
Reverse Osmosis	766,600	9,600	3,330	78,100
Degasification	17,000	200	150	2,100
Chemical Feeding	4,600	600	1,660	20,800
Chemicals	-	12,500	-	12,500
Laboratory	-	190	1,360	6,300
General Plant Requirements	123,700	4,100	320	14,200
Total Plant O&M	911,900	27,690	8,320	128,700

The total operating and maintenance cost of $128,700 per year is equivalent to $0.329 m^3/d ($1,245.87/million gallons) treated, based upon the following unit costs:

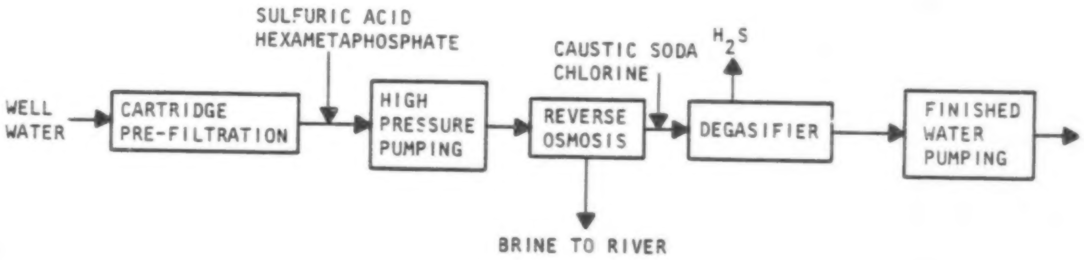
Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.07/kWh	-	617.94
Materials	-	-	147.05
Labor	4.47/hr	-	360.02
Sulfuric Acid	0.0509/lb	122.5	52.00
Sodium Hexametaphosphate	0.7695/lb	5.1	32.73
Soda Ash	0.1838/lb	20.3	31.12
Chlorine	0.2614/lb	2.3	5.01
Total			1,245.87

BRYN MAWR WATER COMPANY, VERO BEACH, FLORIDA

This utility provides water to developing properties located in Port St. Lucie near Vero Beach, Florida. The water company operates a 454.2 m^3/d (120,000 gpd) capacity water treatment facility; in 1981 the average volume of treated water was 162.4 m^3/d (42,900 gpd). Groundwater is treated using cartridge filtration and chemical addition prior to reverse osmosis, chlorination, and degasification. Treatment is provided to demineralize and assure disinfection. A process flow diagram showing the points of chemical addition is shown on Figure B-12.

PLANT DESIGN CAPACITY = 454.2 m^3/d (120,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1981 = 162.4 m^3/d (42,900 GPD)



WELL WATER
CARTRIDGE PRE-FILTRATION
SULFURIC ACID
HEXAMETAPHOSPHATE
HIGH PRESSURE PUMPING
REVERSE OSMOSIS
BRINE TO RIVER
CAUSTIC SODA
CHLORINE
H_2S
DEGASIFIER
FINISHED WATER PUMPING

Figure B-12. **Bryn Mawr Water Company, Vero Beach, Florida.**

The treatment facilities are housed in a 9.15 x 13.7 m (30 x 45 ft) concrete block structure. Supplied by three artesian wells, raw water first passes through a cartridge filter to remove sand and other particles. Sulfuric acid is added for pH adjustment, and hexametaphosphate is added to prevent scaling of the reverse osmosis membranes. Two high-pressure pumps feed the membranes. From the reverse osmosis system, product water is metered and caustic soda is added to readjust the pH. Chlorine is then added for disinfection. Product water is pumped to a degasification tower to remove sulfides in the form of hydrogen sulfide gas. Finished water is pumped to the distribution system. Under normal operation, about 75 percent of the raw water passes through the reverse osmosis membranes as product water. The remaining 25 percent is brine which is discharged to Indian River.

Construction of the treatment facilities was originally completed in 1972 followed by major renovations in 1978-1979. Data on the construction costs are unavailable. Design criteria for the principal treatment facilities are as follows:

Reverse Osmosis System	27 units - 15.24 cm (6 inch) spiral-wound membranes, 28.12 kg/cm^2 (400 psi) operating pressure, 75 percent recovery
Degasifier	1.52 m (5 ft) diameter, 6.1 m (20 ft) tall fiberglass tank

Operation and maintenance requirements and costs based upon year 1980 conditions were:

Process	Process Energy kWh/yr	Maintenance Material, \$/yr	Labor, hr/yr	Total O&M Cost, \$/yr
Pre-Filtration	-	150	80	500
Reverse Osmosis	194,700	650	380	10,100
Degasification	11,600	-	20	550
Chemical Feeding	12,500	90	160	1,280
Chemicals	-	-	-	4,200
Laboratory	-	-	160	690
General Plant Requirements	445,400	-	250	18,900
Total Plant O&M	664,200	890	1,050	36,200/yr

The total cost is equivalent to \$0.611/m^3 (\$2,315.60/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.04/kWh	-	1,696.70
Materials	-	-	56.80
Labor	4.34/hr	-	288.50
Sulfuric Acid	0.05/lb	306.0	127.60
Hexametaphosphate	1.33/lb	9.8	108.70
Caustic Soda	0.16/lb	19.2	25.60
Chlorine	0.26/lb	5.4	11.70
Total			2,315.60

WURTSMITH AIR FORCE BASE, MICHIGAN

The Air Force operates a 5,178 m^3/d (1,368,000 gpd) water treatment facility; in 1981 the average volume of treated water was 5,178 m^3/d (1,368,000 gpd). The treatment facility was installed as part of a USAF research project assigned to promulgate a solution for groundwater contamination at a site on the base. None of the water treated at the Wurtsmith AFB research facility is consumed at the base. Instead, all treated groundwater is discharged to nearby surface water.

Groundwater is treated using air stripping, granular activated carbon filters, and chlorination. Treatment is provided to remove trichloroethylene and to assure disinfection. A process flow diagram is shown on Figure B-13.

All treatment equipment is housed in a 6.1 x 6.1 m (20 x 20 ft) single-story wood frame structure. Raw water from four wells is chlorinated as it is pumped to two air stripping columns operated in series. The 1.52 m (5 ft) diameter, 9.1 m (30 ft) tall columns are randomly packed with 5.49 m (18 ft) of plastic media and supplied with countercurrent forced air from two blowers. The action of the water splashing over the plastic media as the forced air passes upward helps to volatilize and remove organics from the raw water. The water then flows to a storage reservoir which can also be aerated for maximum volatilization before the water enters the carbon adsorption system. Following activated carbon treatment, finished water is discharged to storm sewers, which in turn discharge to surface water.

Installation of the treatment facilities was completed in phases during 1981-1982. Data are unavailable on construction costs of the system as a whole. Design criteria for the principal treatment facilities are as follows:

Packed Column Air Stripper	2 units - 1.52 m (5 ft) diameter, 9.1 m (30 ft) tall with 5.49 m (18 ft) of randomly packed plastic media, forced air blowers

Operation and maintenance requirements and costs based upon 1981 conditions were:

PLANT DESIGN CAPACITY = 5,178 m^3/d (1,368,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1982 = 5,178 m^3/d (1,368,000 GPD)

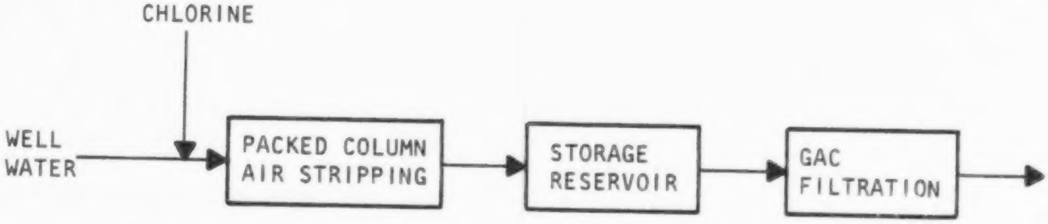

CHLORINE
WELL WATER
PACKED COLUMN AIR STRIPPING
STORAGE RESERVOIR
GAC FILTRATION

Figure B-13. **Wurtsmith Air Force Base, Michigan.**

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Air Stripper	8,200	0	2,300	10,500
Aeration and Reservoir	0	0	800	800
Carbon Filters	*	*	*	380,000
Chlorine Feeding	0	0	100	100
Chlorine	-	-	-	6,400
Laboratory	-	-	500	500
Laboratory Service Agreement	*	*	*	18,000
Total Plant O&M	8,200	0	3,700	416,300

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*Contracted to outside services.

The total cost is equivalent to $0.22/m³ ($833.80/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	*	-	16.50
Materials	-	-	0
Labor	*	-	7.30
Chlorine	1.10/lb	1.4	12.90
Carbon	0.80/lb	401.6/mg Treated	321.20
Outside Services	-	-	475.90
Total			833.80

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*Data unavailable.

TOWN OF GILA BEND, ARIZONA

The Town of Gila Bend is located in Southwestern Arizona. The water supply is groundwater which has a fluoride content between 4.5 and 6.0 mg/L, depending upon the particular well which is sampled. Treatment for fluoride removal is provided using activated alumina. The design capacity of the plant is 2,839 m³/d (0.75 mgd), with an average daily flow rate of 1,790 m³/d (0.473 mgd). A process flow diagram is presented in Figure B-14.

The treatment facilities were constructed in 1978, and consist of two pressure, activated alumina contactors, caustic and acid storage tanks, and a lined brine evaporation pond. The construction cost of the treatment facilities was $188,000, and for the pond was $72,000. Design criteria for the treatment facilities are as follows:

PLANT DESIGN CAPACITY = 2,839 m^3/d (750,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 1,790 m^3/d (473,000 GPD)

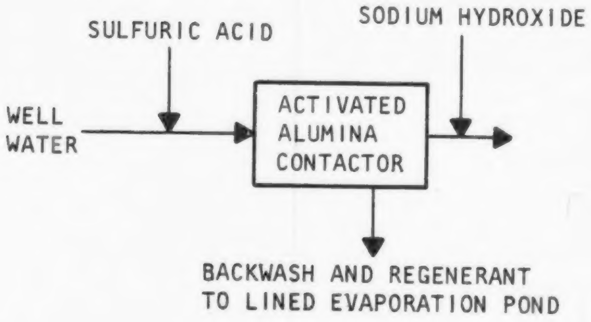
SULFURIC ACID
SODIUM HYDROXIDE
WELL WATER
ACTIVATED ALUMINA CONTACTOR
BACKWASH AND REGENERANT TO LINED EVAPORATION POND

Figure B-14. Town of Gila Bend, Arizona.

Activated Alumina Contactors	3.05 m (10 ft) in diameter rubber-lined pressure vessels, 10.64 m^3, (380 cu ft) of activated alumina in each contactor
Activated Alumina	Alcoa F-1 (-28, +48 mesh)
Acid and Caustic Storage	22.71 m^3 (6,000 gal), horizontal steel storage tank located outside
	0.378 m^3 (100 gal) day tank located inside
Brine Evaporation Pond	Volume not stated

Operation and maintenance requirements during 1981 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Activated Alumina and Chemical Feed	12,030*	2,180	828	11,300
Chemicals	-	-	-	10,000
Total Plant O&M	12,030	2,180	828	21,300

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*Process energy is 10,380 kWh/yr and building energy is 1,650 kWh/yr.

These requirements are based upon a total of 31 regenerations per year, or approximately one regeneration every 12 days.

The total operation and maintenance cost of $21,300/yr is equivalent to $0.033/$m^3$ ($123.44/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.06/kWh	-	4.18
Materials	-	-	12.64
Labor	10.20/hr	-	48.95
Chemicals		-	57.67
Total			123.44

DELL CITY, TEXAS

Dell City, Texas, is located in the western Texas panhandle, about 5 km (3 miles) south of the New Mexico border. The City treats groundwater using an electrodialysis reversal (EDR) plant supplied by Ionics, Inc. The system is designed to treat water with a total dissolved solids content of 3,175 mg/L and a sulfate content of 1,700 mg/L. The design capacity of the plant is 378.5 m^3/d (100,000 gpd), and the current average daily flow treated is 285.4 m^3/d (75,400 gpd). A process flow diagram is shown in Figure B-15.

The treatment facilities are housed, including the hydrochloric acid and hypochlorite storage and feed facilities, the pressure filter, and the electrodialysis stacks. Hydrochloric acid (5% solution) is used for stack cleaning about once a week. This operation takes approximately one hour and consists of recirculation of the acid solution through the stacks. After acid cleaning, the stacks are rinsed for 30-45 minutes with raw water. Discharge to a municipal sewer is used for disposal of both brine and rinse water produced after the acid washing.

The EDR facilities were installed in an existing building in 1976, for a total cost of $100,000.

Design criteria for the treatment facilities are as follows:

Electrodialysis Stacks	4 - each with 450 cell pairs. System is designed to produce 475 mg/L product water.
Chlorination	Calcium hypochlorite.

Operation and maintenance requirements and costs during 1982 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Electrodialysis	317,180	13,435	1,245	35,520
Chemicals	-	-	-	2,890
Total Plant O&M	317,180	13,435	1,245	38,410

The total operation and maintenance cost of $38,410 is equivalent to $0.388/$m^3$ ($1,469.27/million gallons) treated, based upon the following unit costs:

PLANT DESIGN CAPACITY = 378.5 m^3/d (100,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 285.4 m^3/d (75,400 GPD)

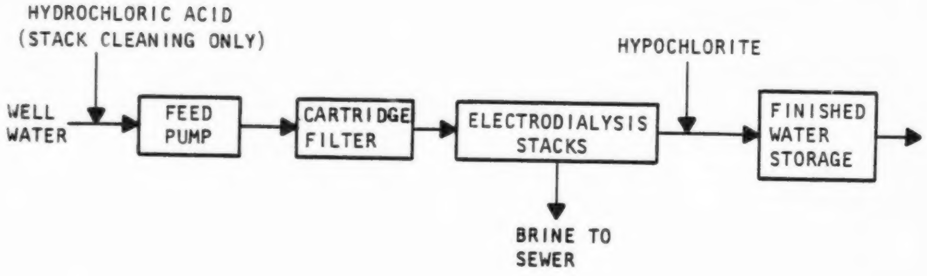
HYDROCHLORIC ACID
(STACK CLEANING ONLY)
WELL WATER
FEED PUMP
CARTRIDGE FILTER
ELECTRODIALYSIS STACKS
BRINE TO SEWER
HYPOCHLORITE
FINISHED WATER STORAGE

Figure B-15. Dell City, Texas.

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.05/kWh	-	606.69
Materials	-	-	513.96
Labor	5.00/hr	-	238.06
Hydrochloric Acid	56.85/55 gallon drum	*	51.65
Calcium Hypochlorite	131.00/100 lb of dry chemical	5.5	58.91
Total			1,469.27

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*Hydrochloric acid is used for stack cleaning only. Approximately twenty-four 55 gallon drums are used annually.

CITY OF BRONSON, KANSAS

The City of Bronson, Kansas, is located approximately 145 km (90 miles) south southwest of Kansas City. Surface water is treated using a Neptune Microfloc Water Boy Model 133. This package plant provides chemical feed and rapid mix, flocculation, sedimentation including tube settlers, and dual media gravity filtration. The design capacity of the plant is 545 m^3/d (144,000 gpd), and the average flow rate in 1981 was 219.9 m^3/d (58,110 gpd). A process flow diagram is shown in Figure B-16.

The treatment facilities are housed in a metal building, and the building is located next to a sand filter which has been converted to serve as a clearwell. Chlorination is accomplished using a gas chlorinator. As shown in the process flow diagram, alum, polymer, and soda ash are added to the rapid mix unit, and chlorine is added prior to rapid mix. The addition of soda ash is necessary to add sufficient alkalinity for the alum to react.

Design critera for the treatment facilities are as follows:

Plant Design Capacity	545 m^3/d (144,000 gpd)
Flocculator Volume	4.4 m^3 (158 cu ft)
Filter Area	1.86 m^2 (20 sq ft)
Filtration Rate	12.2 m^3/m^2/h (5 gpm/sq ft)

The treatment facilities were constructed in 1976, for a cost of $93,000. This cost included the package treatment plant, conversion of the slow sand filter to a clearwell, new raw water pumps, the metal building, and minor sitework.

Operation and maintenance requirements during 1981 were:

PLANT DESIGN CAPACITY = 545 m^3/d (144,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 - BRONSON = 219.9 m^3/d (58,110 GPD)
RICHMOND = 234.8 m^3/d (62,030 GPD)
JEFFERSON COUNTY = 30.3 m^3/d (8,000 GPD)

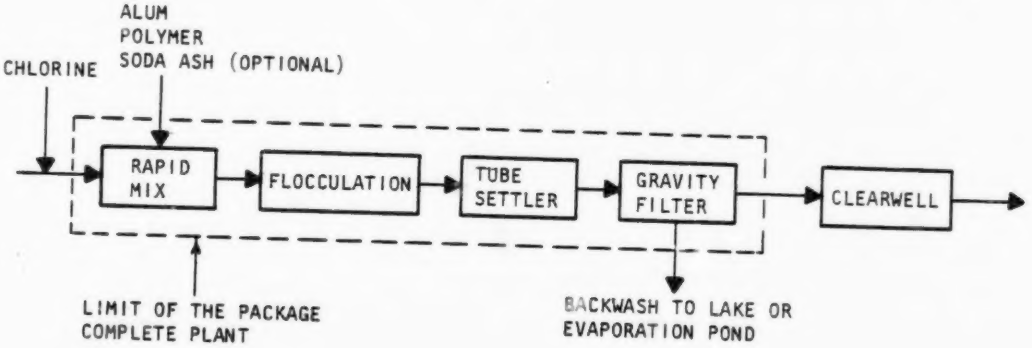
ALUM
POLYMER
SODA ASH (OPTIONAL)
CHLORINE
RAPID MIX
FLOCCULATION
TUBE SETTLER
GRAVITY FILTER
CLEARWELL
LIMIT OF THE PACKAGE COMPLETE PLANT
BACKWASH TO LAKE OR EVAPORATION POND

Figure B-16. **Bronson, Richmond, and Jefferson County Rural Water District No. 11, Kansas.**

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Complete Treatment	49,650	3,080	263	9,410
Alum				1,450
Polymer				1,400
Soda Ash				1,430
Chlorine				110
Total Plant O&M	49,650	3,080	263	13,800

The total operation and maintenance cost of $13,800/yr is equivalent to $0.172/m³ ($650.62/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.0614/kWh	-	143.80
Materials	-	-	145.21
Labor	11.71/hr	-	154.64
Alum	0.1704/lb	48.3	68.36
Polymer	8.00/lb	1.0	66.00
Soda Ash	0.1436/lb	56.3	67.42
Chlorine	0.2795/lb	2.2	5.19
Total			650.62

CITY OF RICHMOND, KANSAS

The City of Richmond, Kansas, is located 113 km (70 miles) south of Kansas City. The City treats a lake water supply using a Neptune Microfloc Water Boy Model 133. This package plant provides chemical feed and rapid mix, flocculation, sedimentation including tube settlers, and dual media gravity filtration. The design capacity of the plant is 545 m³/d (144,000 gpd), and the average flow rate in 1981 was 234.8 m³/d (62,030 gpd). A process flow diagram is shown in Figure B-16, which was presented previously in the write-up for the City of Bronson, Kansas.

The package treatment facilities were installed in 1970, as a replacement for a slow sand filter. The installation entailed construction of a metal building over an existing clearwell, and installation of the package plant and gas chlorination facilities in the building. The capital cost of the plant (1970 dollars) was $19,500, with an additional $25,800 expended for the building and modifications to the existing clearwell.

Design criteria for the treatment facilities are as follows:

Plant Capacity	545 m³/d (144,000 gpd)
Flocculator Volume	4.4 m³ (158 cu ft)
Filter Area	1.86 m² (20 sq ft)
Filtration Rate	12.2 m³/m²/1 (5 gpm/sq ft)

Operation and maintenance requirements during 1981 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Complete Treatment	56,900	3,930	690	13,920
Chemicals	-	-	-	1,550
Total Plant O&M	56,900	3,930	690	15,470

The total operation and maintenance cost of \$15,470/yr is equivalent to \$0.18/m^3 (\$682.87/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.0859/kWh	-	215.90
Materials	-	-	173.37
Labor	7.40/hr	-	225.31
Alum	Unavailable	67.2	-
Soda Ash	Unavailable	3.8	-
Polymer	Unavailable	0.8	-
Chlorine	Unavailable	1.4	-
All Chemicals Combined			68.29
Total			682.87

JEFFERSON COUNTY RURAL WATER DISTRICT NO. 11, KANSAS

This utility serves two subdivisions located in western Jefferson County, approximately 81 km (50 miles) west of Kansas City. The source is a lake, and treatment is provided by a Neptune Microfloc Water Boy Model 133. This package plant includes chemical feed and rapid mix, flocculation, sedimentation including tube settlers, and dual media gravity filtration. The plant design capacity is 545 m^3/d (144,000 gpd), and the average daily flow treated in 1981 was 30.3 m^3/d (8,000 gpd). A process flow diagram is shown in Figure B-16, which was presented previously in the write-up for the City of Bronson, Kansas.

The treatment facilities are located in a building, as are two steel tanks which serve as clearwells. No information was obtained during the site visit on the original construction cost. This information was not available, because the treatment facilities were originally constructed by a private developer, and were then later turned over to the Jefferson County Rural Water District No. 11.

Design criteria for the treatment facilities are as shown following:

Plant Capacity	545 m^3/d (144,000 gpd)
Flocculator Volume	4.4 m^3 (158 cu ft)
Filter Area	1.86 m^2 (20 sq ft)
Filtration Rate	12.2 m^3/m^2/h (5 gpm/sq ft)

Operation and maintenance requirements during 1981 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Treatment	29,480	400	510	7,890
Alum				210
Polymer				160
Anthrafilt				20
Chlorine				60
Total Plant O&M	29,480	400	510	8,340

The total operation and maintenance cost of $8,340/yr is equivalent to $0.75/$m^3$ ($2,843.76/million gallons) treated, based on the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.0895/kwh	-	904.08
Materials	-	-	138.40
Labor	9.50/hr	-	1,650.56
Alum	-	49.0 mg/L	69.88
Polymer	-	0.8 mg/L	54.81
Anthrafilt	-	50.0 lb/yr	6.85
Chlorine	-	8.2 mg/L	19.18
Total			2,843.76

CITY OF RIALTO, CALIFORNIA

The City of Rialto is located 77 km (48 miles) east of Los Angeles. One of the City's water treatment facilities, the Cedar Avenue Filtration Plant, uses pressure diatomaceous earth filters to treat water from a mountain stream. Prior to treatment, the water passes through a hydroelectric plant, and is delivered to the water treatment plant under some pressure, which minimizes the amount of on-site pumping required. The plant design capacity is 5,299 m^3/d (1.4 mgd), and the average daily flow treated in 1982 was 4,341 m^3/d (1.147 mgd). A process flow diagram is shown in Figure B-17.

The treatment facilities include the diatomaceous earth filter, DE storage tank, DE body feed pump, and gas chlorination equipment. These facilities are installed in a 9.14 x 9.14 m (30 x 30 ft) building.

Design criteria for the treatment facilities are:

PLANT DESIGN CAPACITY = 5,299 m^3/d (1,400,000 GPD)

AVERAGE DAILY VOLUME TREATED IN 1982 = 4,341 m^3/d (1,147,000 GPD)

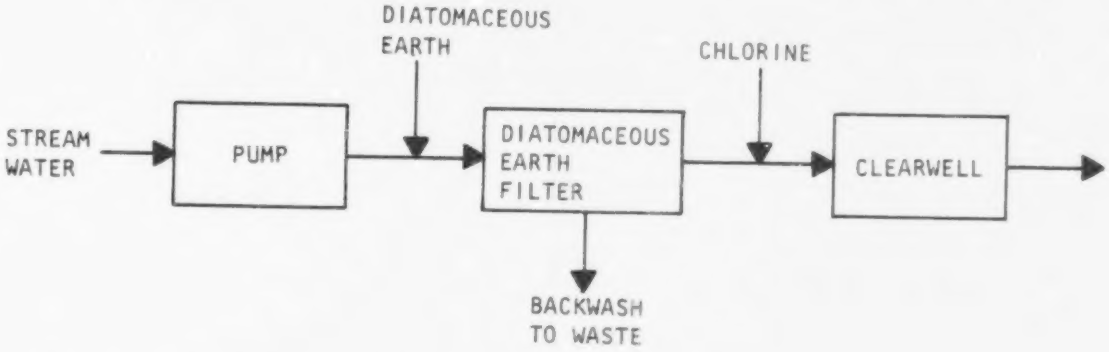
DIATOMACEOUS EARTH
CHLORINE
STREAM WATER
PUMP
DIATOMACEOUS EARTH FILTER
CLEARWELL
BACKWASH TO WASTE

Figure B-17. City of Rialto, California.

Diatomaceous Earth Filter	
Design Capacity	5,299 m^3/d (1,400,000 gpd)
Number of Filters	1
Total Filter Area	71.1 m^2 (765 sq ft)
Filtration Rate	3.1 m^3/m^2/h (1.27 gpm/sq ft)
Diatomaceous Earth	Eagle Picher FW14
Diatomaceous Earth Storage Tank	
Volume	2.65 m^3 (700 gal)
DE Concentration	0.12 kg/L (1 lb/gal)
Chlorination	Gas feed
Filtered Water Storage	37.85 m^3 (10,000 gal)

The filtration facilities, including the filtered water storage tank and the building were constructed in 1967 for $50,000.

Current operational procedures are summarized following:

- Precoat = 0.635 kg/m^2 (0.13 lb DE/sq ft)
- Body feed = 0.782 kg/m^2 (0.16 lb DE/sq ft)
- Filter run time = 120 hr
- Backwash = 1.89 m^3 (500 gal/backwash)

Backwash water flows to one of two 2.44 x 12.2 x 1.83 m (8 x 40 x 6 ft) deep concrete sumps. These pits are sloped on one end to grade, which allows a front-end loader to remove the dried sludge once per year. The dried sludge is trucked to a local landfill. The plant is removed from service for one week per year for maintenance, which includes removing the tubes fom the filter and acid washing them, as well as routine maintenance on pumps and instrumentation.

Operation and maintenance requirements during 1982 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Treatment	196,800	2,720	509	21,550
Diatomaceous Earth	-	-	-	2,950
Chlorine	-	-	-	740
Total Plant O&M	196,800	2,720	509	25,240

The total operation and maintenance cost of $25,240/yr is equivalent to $0.0159/$m^3$ ($60.26/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.0664/kWh	-	31.18
Materials	-	-	6.50
Labor	11.32/hr	-	13.76
Diatomaceous Earth	-	6.9	7.05
Chlorine	-	0.73	1.77
Total			60.26

CITY OF SAFFORD, ARIZONA

The City of Safford is located 242 km (150 miles) east of Phoenix. One of the City's treatment facilities is an automatic backwash gravity sand filter which treats surface water from an open supply reservoir. The plant design capacity is 3,407 m^3/d (900,000 gpd), and the average daily volume treated in 1982 was 590.5 m^3/d (156,000) gpd. However, the plant is only run during portions of the year when runoff is low (May to September) resulting in low raw water turbidity in the storage reservoir. Operation data presented in this write-up is based on a projection of twelve months' operation, using current operating data as a basis. A process flow diagram is shown in Figure B-18.

The sand filter is a Permutit Automatic Valveless Gravity Filter, which is installed in a concrete structure with a concrete cover. There is only one filter, and there is no access through the concrete cover. The only access is through manholes located in the side of the concrete structure. Chlorination is accomplished using chlorine gas from a 454 kg (100 lb) cylinder.

Design criteria for the treatment facilities are:

Filter	
Design Rating	3,407 m^3/d (0.9 mgd)
Size	3.81 x 7.62 m (12.5 x 25 ft)
Media	Sand
Filtration Rate	4.88 m^3/m^2/h (2 gpm/sq ft)
Chlorination	Gas

Controls for the filter and the chlorine storage and feed facilities are located in a 4.57 x 4.57 m (15 x 15 ft) block building. During normal operation, the filter is backwashed every three days of operation. Backwash water is directed to a reservoir, where it either evaporates or is used for golf course irrigation.

Operation and maintenance requirements and costs during 1982 (based upon projection of current operations to a full-year basis) were:

PLANT DESIGN CAPACITY = 3,407 m^3/d (900,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1982 = 590.5 m^3/d (156,000 GPD)

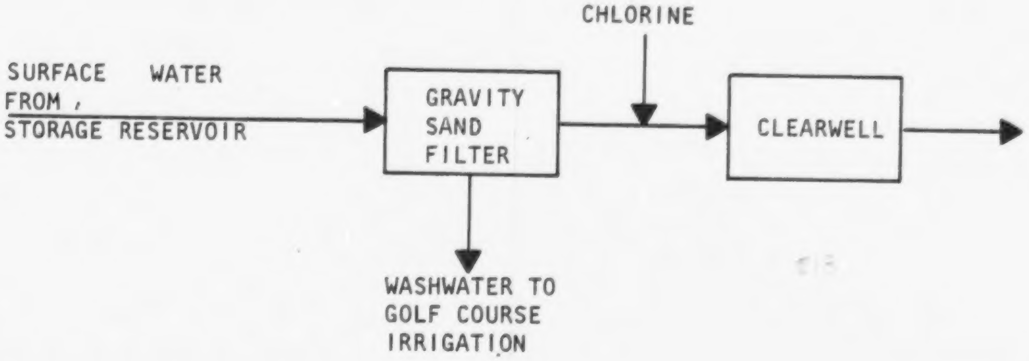
CHLORINE
SURFACE WATER FROM STORAGE RESERVOIR
GRAVITY SAND FILTER
CLEARWELL
WASHWATER TO GOLF COURSE IRRIGATION

Figure B-18. City of Safford, Arizona.

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Filtration and Chlorination	18,000	400	1,040	14,480
Chlorine	-	-	-	710
Total Plant O&M	18,000	400	1,040	15,190

The total operation and maintenance cost of $15,190/yr (projection of existing operation to a full-year basis) is equivalent to $0.070/m³ ($266.76/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.06/kWh	-	18.97
Materials	-	-	7.02
Labor	12.50/hr	-	228.31
Chlorine	0.50/lb	3 mg/L	12.46
Total			266.76

DAVIS DAM, BULLHEAD CITY, ARIZONA

Davis Dam is located on the Colorado River, approximately 121 km (75 miles) southwest of Las Vegas. The treatment facility treats water for use at the Government Camp, for potable water at the Dam, and for a public hose connection at the Dam which is used as a filling location for recreational vehicles. The water supply is from Lake Mojave, which is the impoundment created by Davis Dam. Water is drawn from the lower depths of the lake, and generally has low turbidity (0.6-1.4 NTU). During heavy rainfall periods, the lake water becomes slightly silty. The plant design capacity is 3,785 m^3/d (1 mgd), and the average volume treated during 1981 was 791 m^3/d 0.209 mgd. A process flow diagram is shown in Figure B-19.

The coagulation detention tank, dual-media pressure filters and the chlorinator are located in the transformer support structure of the Dam. The facilities were installed in 1974, primarily because the State of Arizona requires that all surface supplies be filtered and chlorinated. Chlorine is added to the supply pump suction, and the facilities were designed to allow alum addition at this point also. Due to low raw water turbidity and the inability to satisfactorily control the rate of alum addition, there is use of alum prior to filtration. A coagulation detention tank was originally installed to provide five minutes detention time for alum reaction prior to filtration. Water currently flows through this tank, although it serves no purpose. There are three horizontal dual-media pressure filters (anthracite/sand). Backwash flows to a backwash retention tank, where 11.35 kg (25 lb) of alum crystals are added manually after each backwash to improve the settling of silt in the basin. Decant is returned to the Colorado River and sludge is withdrawn every six months with a vacuum truck and taken to a local landfill.

PLANT DESIGN CAPACITY = 3,785 m^3/d (1,000,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981 = 791 m^3/d (209,100 GPD)

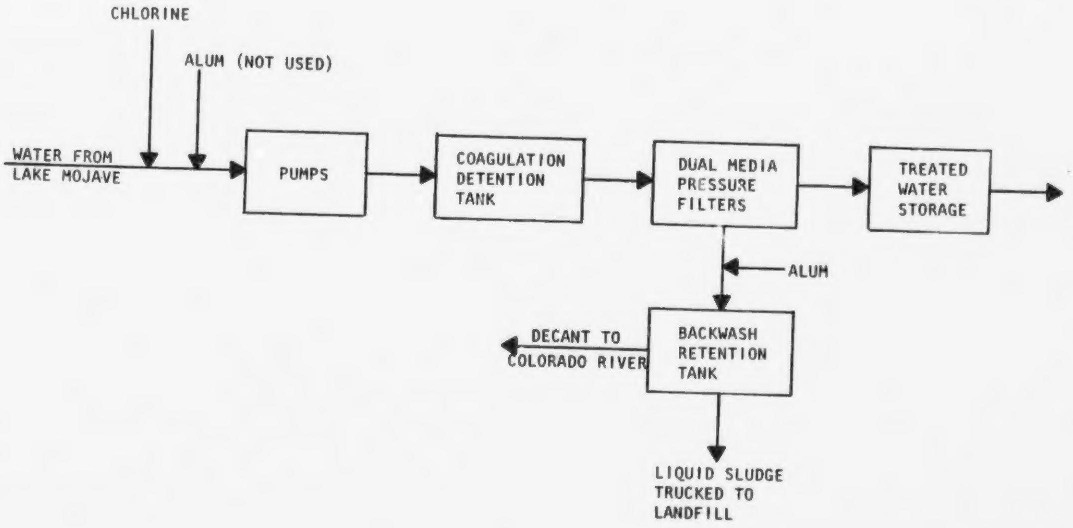
CHLORINE
ALUM (NOT USED)
WATER FROM LAKE MOJAVE
PUMPS
COAGULATION DETENTION TANK
DUAL MEDIA PRESSURE FILTERS
TREATED WATER STORAGE
ALUM
BACKWASH RETENTION TANK
DECANT TO COLORADO RIVER
LIQUID SLUDGE TRUCKED TO LANDFILL

Figure B-19. **Davis Dam, Bullhead City, Arizona.**

Design criteria for the treatment facilities are listed following:

Design Capacity	3,785 m^3/d (1 mgd)
Coagulation Detention Tank	5 min. detention, 1.52 m (5 ft) diameter, 4.57 m (15 ft) long
Pressure Filters	
Number	3
Type	Dual-media
Surface Area Each	3.9 m^2 (42 sq ft)
Diameter	2.13 m (7 ft)
Length	4.11 m (13.5 ft)
Filtration Rate (at Design Capacity)	13.42 m^3/m^2/h (5.5 gpm/sq ft)
Chlorination	Gas - 68.1 kg (150 lb) cylinders
Backwash Retention Tank	215.7 m^3 (57,000 gal)

Operation and maintenance labor requirements are relatively low because the filters automatically backwash, and the entire treatment system has been extremely reliable and low in maintenance.

Operation and maintenance requirements and costs during 1981 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Filtration	119,260	-	138	9,295
Chlorine	-	-	-	700
Alum	-	-	-	180
Total Plant O&M	119,260		138	10,175

The total operation and maintenance cost of $10,175/yr is equivalent to $0.035/$m^3$ ($133.30/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$0.06/kWh	-	93.75
Materials	-	-	0.00
Labor	15.50/hr	-	28.02
Chlorine	0.40/lb	3.0 mg/L	9.17
Alum	0.08/lb	25 lb/backwash	2.36
Total			133.30

CITY OF CASTLE DALE, UTAH - CASTLE VALLEY SPECIAL SERVICE DISTRICT

The City of Castle Dale is approximately 193 km (120 miles) south of Salt Lake City. The water supply is snow melt runoff from nearby mountains, with reservoirs used to impound the runoff prior to treatment. This water supply is also used for agricultural irrigation, and the influent water for the treatment plant is withdrawn from the irrigation ditch. Treatment consists of settling ponds, a flocculator/clarifier, and four gravity sand filters. The design capacity of the plant is 4,921 m^3/d (1.3 mgd), and the average daily flow in 1981-1982 was 1,840 (0.486 mgd). A process flow diagram is shown in Figure B-20.

This treatment facility was originally constructed in 1964, and later modified in 1975. The first stage of the treatment is three earthen settling ponds, which are used to settle out coarse solid material. After settling, chlorine and alum are added prior to an in-line mixer and polymer is added after the mixer. The Eimco flocculator/clarifier was modified in the 1975 expansion by raising the side wall height and adding tube settlers. Next in the treatment process are four gravity sand filters, which backwash automatically on a two-day cycle. Backwash is directed to an earthen lagoon, and decant from this lagoon is returned to the irrigation ditch. Silt is removed from the lagoon every two years and is spread on an adjacent field. Low head pumps are used between the flocculator/clarifier and the filters.

Design criteria for the treatment facilities are listed following:

Settling Basins	
Number	3
Volume	Unknown
Flocculator/Clarifier	
Surface Area	27.9 m^2 (300 sq ft)
Filters	
Type	Gravity
Media	Sand
Number	4
Area Per Filter	6.97 m^2 (75 sq ft)

The flocculator/clarifier, chemical feed facilities, and the filters were originally constructed in 1964 for $210,000. In 1975, a number of plant modifications were made, including raising the walls of the flocculator/clarifier and addition of tube settlers in the flocculator/clarifier.

Operation and maintenance requirements and costs during 1982 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Treatment	269,000	5,020	1,095	38,790
Alum	-	-	-	2,020
Polymer	-	-	-	720
Chloride	-	-	-	850
Total Plant O&M	269,000	5,020	1,095	42,380

PLANT DESIGN CAPACITY = 4,921 m^3/d (1,300,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981/1982 = 1,840 m^3/d (486,000 GPD)

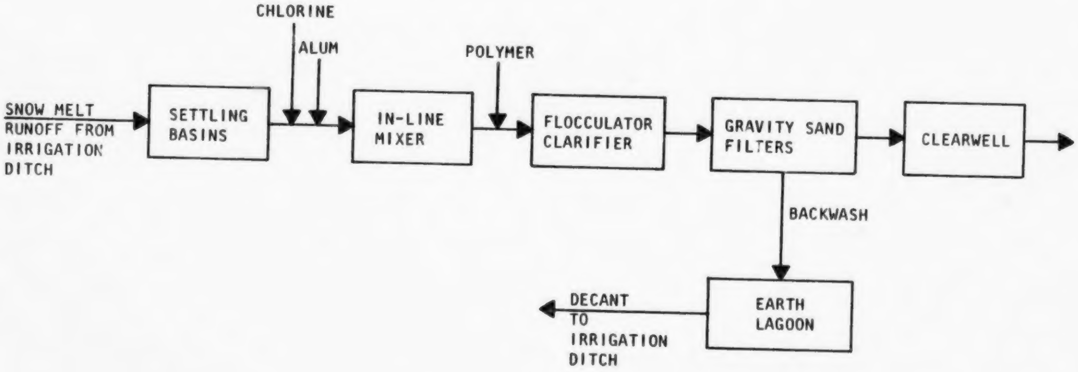
CHLORINE
ALUM
POLYMER
SNOW MELT RUNOFF FROM IRRIGATION DITCH
SETTLING BASINS
IN-LINE MIXER
FLOCCULATOR CLARIFIER
GRAVITY SAND FILTERS
CLEARWELL
BACKWASH
EARTH LAGOON
DECANT TO IRRIGATION DITCH

Figure B-20. City of Castle Dale, Utah - Castle Valley Special Service District.

The total operation and maintenance cost of $42,380/yr is equivalent to $0.063 m^3 ($238.92/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.062/kWh	-	94.02
Materials	-	-	28.30
Labor	15.61/hr	-	96.36
Alum	-	17.0	11.39
Polymer	-	0.11	4.06
Chlorine	-	1.8	4.79
Total			238.92

CITY OF FERRON, UTAH - CASTLE VALLEY SPECIAL SERVICE DISTRICT

The City of Ferron, Utah, is located approximately 193 km (120 miles) south of Salt Lake City. The water supply is snow melt runoff from nearby mountains, with reservoirs used to impound the runoff prior to treatment. The treatment facilities are two parallel package complete treatment plants (Keystone Hydraulic Flocculators), each with a capacity of 1,893 m^3/d (0.5 mgd). The design capacity of the plant is 3,785 m^3/d (1.0 mgd), and in 1981-1982 the average daily volume treated was 2,135 m^3/d (0.564) mgd. A process flow diagram is shown in Figure B-21.

The existing treatment units were installed in 1978 to replace outdated facilities which are no longer used. The construction cost was $344,000, which included the package plants, chemical feed, and a building to house treatment equipment.

Design criteria for the package complete treatment facilities is as follows:

Number of Units	2
Capacity/Unit	1,893 m^3/d (0.5 mgd)
Basin Depths	2.13 m (7 ft)
Flocculator Surface Area	31.6 m^2/unit
Sand Filter Area	14.86 m^2/unit (160 sq ft/unit)

Backwash of the filters is automatically initiated by headloss. A portion of the backwash water flows backward through the settling tubes. Backwash water flows to a lagoon, and decant water is used for irrigation.

Operation and maintenance requirements and costs during 1982 were:

PLANT DESIGN CAPACITY = 3,785 m^3/d (1,000,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981/1982 = 2,135 m^3/d (564,000 GPD)

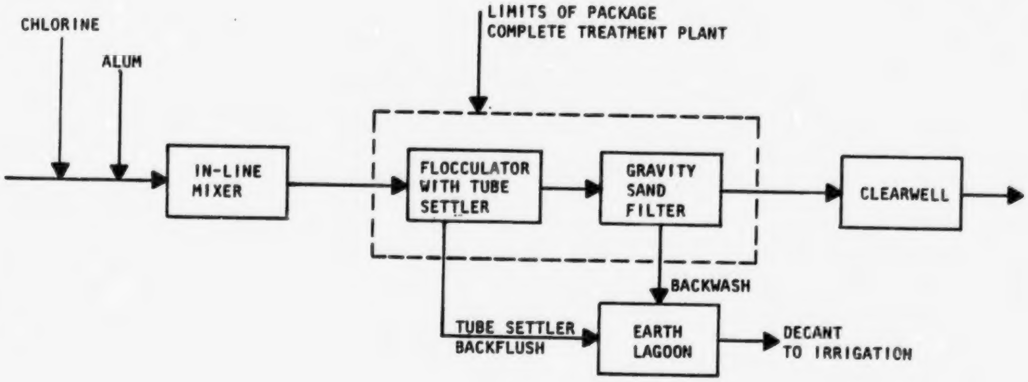
LIMITS OF PACKAGE
COMPLETE TREATMENT PLANT
CHLORINE
ALUM
IN-LINE MIXER
FLOCCULATOR WITH TUBE SETTLER
GRAVITY SAND FILTER
CLEARWELL
BACKWASH
TUBE SETTLER BACKFLUSH
EARTH LAGOON
DECANT TO IRRIGATION

Figure B-21. City of Ferron, Utah - Castle Valley Special Service District.

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Treatment	256,460	2,500	730	29,270
Alum	-	-	-	2,190
Polymer	-	-	-	3,140
Chlorine	-	-	-	680
Total Plant O&M	256,460	2,500	730	35,280

The total operation and maintenance cost of $34,800/yr is equivalent to $0.045/m^3 ($171.33/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.062/kWh	-	77.24
Materials	-	-	12.14
Labor	14.88/hr	-	52.77
Alum	0.08/lb	15.9	10.64
Polymer	4.30/lb	0.42	15.25
Chlorine	0.32/lb	1.2	3.30
Total			171.33

CITY OF ORANGEVILLE, UTAH - CASTLE VALLEY SPECIAL SERVICE DISTRICT

The City of Orangeville is located approximately 193 km (120 miles) south of Salt Lake City. The water supply for the treatment facility is snow melt runoff, which is also used for agricultural irrigation. The plant raw water supply is obtained directly from an irrigation canal. Treatment consists of pretreatment settling and two parallel 1,893 m^3/d (0.5 mgd) package complete treatment plants (Neptune Microfloc Aquarius 112). The total design capacity is 3,785 m^3/d (1.0 mgd), and the average daily volume treated during 1981-1982 was 939 m^3/d (0.248 mgd). A process flow diagram is shown in Figure B-22.

The treatment facilities were constructed in 1979 for a cost of $432,000. This cost includes the concrete pre-settling basins, treatment facilities and a concrete block building.

Design criteria for the package complete treatment facilities are as follows:

Number of Units	2
Capacity/Unit	1,893 m^3/d (0.5 mgd)
Basin Depth	2.44 m (8 ft)
Basin Widths	2.97 m (9.75 ft)
Flocculator Detention Time	17 min/unit
Filter Area	10.4 m^2/unit (112 sq ft/unit)

PLANT DESIGN CAPACITY = 3,785 m^3/d (1,000,000 GPD)
AVERAGE DAILY VOLUME TREATED IN 1981/1982 = 939 m^3/d (248,000 GPD)

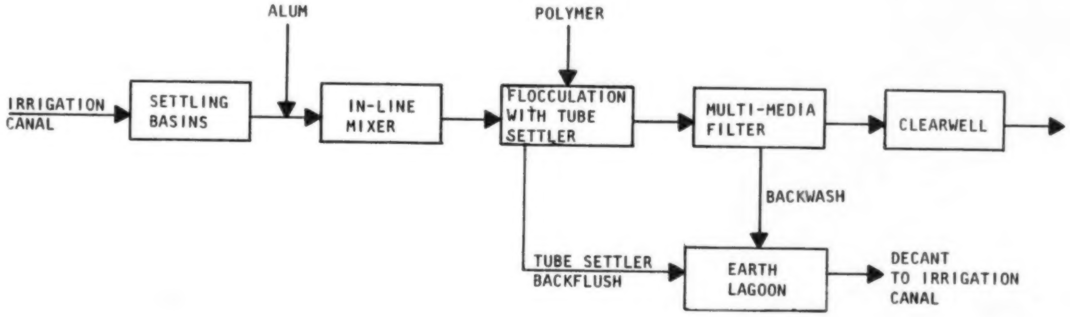
ALUM
POLYMER
IRRIGATION CANAL
SETTLING BASINS
IN-LINE MIXER
FLOCCULATION WITH TUBE SETTLER
MULTI-MEDIA FILTER
CLEARWELL
BACKWASH
TUBE SETTLER BACKFLUSH
EARTH LAGOON
DECANT TO IRRIGATION CANAL

Figure B-22. City of Orangeville, Utah - Castle Valley Special Service District.

Filter backwash is automatically initiated by headloss, and a portion of the filter backwash is also used to backflush the tube settlers. Backwash water flows to an earthen lagoon, and decant from this lagoon is returned to the irrigation canal. Sludge from the lagoon is removed yearly and applied to an adjacent field.

Operation and maintenance requirements and costs during 1982 were:

Process	Process Energy kWh/yr	Maintenance Material, $/yr	Labor, hr/yr	Total O&M Cost, $/yr
Treatment	189,400	2,910	730	25,520
Alum	-	-	-	1,140
Polymer	-	-	-	90
Chlorine	-	-	-	230
Total Plant O&M	189,400	2,910	730	26,980

It should be noted in the above that electrical costs include both process and building requirements.

The total operation and maintenance cost of $29,100/yr is equivalent to $0.079/m^3 ($298.00/million gallons) treated, based upon the following unit costs:

Component	Unit Cost	Chemical Dosage, mg/L	$/Million Gallons Treated
Electricity	$ 0.062/kWh	-	129.73
Materials	-	-	32.15
Labor	14.88/hr	-	120.00
Alum		18.9	12.59
Polymer		0.027	0.99
Chlorine		1.0	2.54
Total			298.00

MCFARLAND MUTUAL WATER COMPANY, MCFARLAND, CALIFORNIA

McFarland is a small town located approximately 40 km (25 miles) north of Bakersfield. Due to high groundwater nitrate concentrations, a strong base ion exchange treatment facility was recently constructed. This plant has a design capacity of 3,785 m^3/d (1.0 mgd). A process flow diagram is shown in Figure B-23.

This treatment facility was completed in November, 1983, for a construction cost of $276,600, including 1.53 m (5 ft) of media in each contactor.

Design criteria for the treatment facilities are as follows:

PLANT DESIGN CAPACITY = 3,785 m^3/d (1 MGD)
CURRENT OPERATION RATE = 1,893 m^3/d (0.5 MGD)

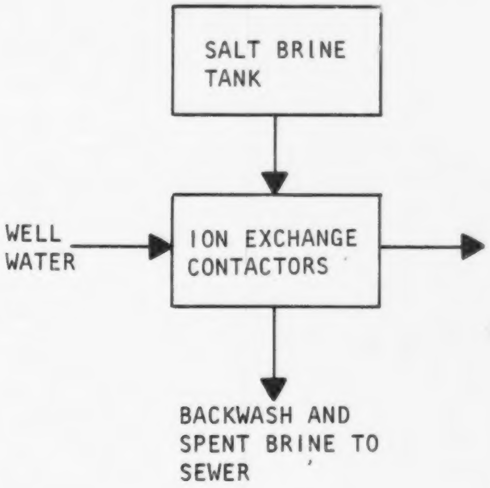
SALT BRINE TANK
WELL WATER
ION EXCHANGE CONTACTORS
BACKWASH AND SPENT BRINE TO SEWER

Figure B-23. **McFarland, California - McFarland Mutual Water Company.**

Plant Capacity	1 mgd
Ion Exchange Contactors	
Number	3
Resin Type	Strong base (Duolite A-101D)
Diameter	1.82 m (6 ft)
Bed Depth	1.53 m (5 ft)
Resin Volume	3.96 m^3/contactor (141.4 cu ft/contactor)
Regeneration Brine Concentration	6%

During the first six months of operation, this plant will be operated with a smaller resin volume and lower flow rate than the plant design capacity. During this initial testing, the resin depth will be 0.92 m (3 ft) and the flow rate will be 1,635-1,908 m^3/d (0.43-0.50 mgd). After completion of this initial testing, the resin depth will be increased to the design depth of 1.53 m (5 ft) and the flow rate will be increased to the design rate of 3,785 m^3/d (1 mgd).

The plant has been designed to operate at the 3,785 m^3/d (1 mgd) design rate with two of the three contactors in operation, and the third contactor maintained as a standby. The projected quality of the final plant product water is 30 mg/L as nitrate, which will be obtained by blending. Rinse water and spent brine will be discharged to the sanitary sewer system.

Because the treatment facilities were first placed into operation in November, 1983, no reliable operating cost information is available. Projected costs for the first year of operation, based upon 6 months at 1,635-1,908 m^3/d (0.43-0.50 mgd) and 6 months at 3,785 m^3/d (1 mgd), are:

Component	Unit Cost	$/yr	$/Million Gallons Treated*
Electricity	$ 0.093/kWh	5,260	19.22
Maintenance Materials, $/yr	-	6,860	25.06
Salt	31.50/ton	17,800	65.02
Resin	137/cu ft	5,761	21.05
Total			130.35

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*Based on average annual flow rate of 2,839 m^3/d (0.75 mgd).

No labor is included in the projections because an EPA technician will be at the plant site during the first year of operation, and the utility did not have to add additional personnel when this plant was placed in operation. Electricity is based on calculations of additional energy required for the well pump to overcome the headloss through the anion exchange plant.